MODELING THE COMPLEXITY OF SUSTAINABLE CITIES: THE INTERDEPENDENCE BETWEEN INFRASTRUCTURE SYSTEMS AND THE SOCIOECONOMIC ENVIRONMENT

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To my wife

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LIST OF SYMBOLS AND ABBREVIATIONS

ABM	Agent-based model
BAU	Business as usual
BIC	Bayesian Information Criterion
CSM	Conventional storm water control management
DCE	Discrete choice experiment
LC	Latent class
LID	Low-impact development
MSD	More sustainable development
TOD	Transit-oriented development
WTP	Willingness to pay

SUMMARY

As a critical component of the city, urban infrastructures emerge through the interactions with the socioeconomic environment. Managing the complexity behind the interactions can make the city more sustainable. By this, we mean if we provide more sustainable amenities that people desire, a greater adoption of more sustainable infrastructures will likely occur. Two categories of infrastructure have emerged in recent years as exemplars of more sustainable development: green infrastructure and transit-oriented development. At the same time, new digital tools have emerged to better predict market acceptance of these infrastructures. This dissertation employs agent-based modeling, a latent-class analysis of survey results, and an online survey to model the potential of adoption of these infrastructures and the public benefits. The principal research content of the dissertation consists of two parts. First, understanding social preference and adoption of green infrastructure (e.g., low-impact development (LID) to control storm water), and transit-oriented development (TOD) to reduce car dependence and incentivize denser land use; Second, by developing an urban model that accounts for the complexity of the urban system, the purpose is to predict the emergent property of the city (e.g., land use, water consumption, tax revenues and carbon emissions). These two aspects constitute the research content of this dissertation. The principal findings of the dissertation are: 1) the use of digital feedback tools to inform the modeling of complex urban systems; 2) the future development of the metro Atlanta area can be more compact and sustainable with implementations of LID, TOD, and the proper policy.

This dissertation consists of four sections. In the first section, I have developed an agent-based model (ABM) to predict the land use pattern. The ABM is an approach

suited to simulating and understanding the dynamics of the complex system. To reduce the complexity and uncertainty of the ABM, the model simulates the decisions and interaction of agents (i.e., home buyer, the developer and the local government) at the neighborhood scale. The output of the ABM serves as the baseline scenario of land use pattern for evaluating the effect of tax investment and fees on the adoption of green infrastructure designs and more compact land use patterns.

Second, with the help of the ABM, I evaluated and compared the policies (i.e., impact fees, subsidy) on the adoption of green infrastructure designs and more compact land use pattern. I developed a more sustainable development (MSD) scenario that introduces an impact fee that developers must pay if they choose not to use LID (i.e., rainwater harvesting, porous pavement) to build houses or apartment homes. Model simulations show homeowners selecting apartment homes 60% of the time after 30 years of development in MSD. In contrast, only 35% homeowners selected apartment homes after 30 years of development in a business as usual (BAU) scenario where there is no impact fee for LID. The increased adoption of apartment homes results from the lower cost of using LID (i.e., rain garden, native vegetation and porous pavements) in public spaces and improved quality of life for apartment homes relative to single-family homes. The MSD scenario generates more tax revenues and water savings than does BAU.

Third, as an initial effort to calibrate the home buyer's preference for community design in the ABM, I developed an analytic model based on an existing community preference survey. The data available for this effort is from National Association of Realtors' 2011 community preference survey. I applied a latent class choice model to this data, and discovered four classes of individuals that reveal distinctive behaviors when choosing smart growth neighborhoods, based on the interplay between aspects of community design, socioeconomic characteristics and personal attitudes. Linking the results of the latent class choice to an agent-based market diffusion model enables planners to evaluate the effectiveness of a proposed smart growth neighborhood design in inducing less sprawling development.

In the fourth section, I developed a survey that focuses on preferences of metropolitan Atlanta residents for LID and TOD. With the responses collected using Mechanical Turk, I developed a latent-class residential community choice model of four distinctive classes that reveal heterogeneous preferences for community designs. Spatial distribution of the four classes was mapped out to visualize the locations of the demand for different community designs in metropolitan Atlanta. The analysis of the impact of increase in housing price on the adoption of LID and TOD shows a low risk of investing in LID and TOD in metro area. Residents are willing to adopt the community with LID and TOD as compared to the corresponding one without LID and TOD. It turns out that LID and TOD have a great potential for adoption in metro Atlanta. Further, I integrated the individual residential community choice simulation into an agent-based market diffusion model to predict the emergent land use pattern and explore polices that can drive the adoption of more compact development. Results show that the current policy requiring single-family houses to implement LID based on individual sites should be switched to one that requires community-based LID for single-family houses. Such a policy switch will lead to a higher adoption of apartment homes with LID and TOD. Lastly, I estimated a 28% carbon emission reduction from more compact development driven by LID and TOD.

This thesis is the very beginning of using digital feedback tools to anticipate market responses to more sustainable development alternatives. On the basis of the progress made in this dissertation, future work is recommended in terms of the development of an integrated platform that supports the integration of individual modules (e.g., land use, traffic simulation, air quality, and water resource management) for modeling the complexity, big data analytic techniques (e.g., Twitter, GPS data, sensors) for uncovering the interdependencies between infrastructures and socioeconomic development, and the exploration of sustainability metrics for public communication to build citizen capacity for sustainable cities.

CHAPTER 1

INTRODUCTION

Sustainable urban development is critical to mitigate human impacts on both local and global environment.[1] Unfortunately, sprawling, low-density development, especially in North American cities, is raising an increasing number of environmental concerns.[2, 3] These concerns include a loss of land resources and biodiversity, the increase in extreme heat events,[4] pollution and greenhouse gas emissions, growing traffic congestion, and an added burden on materials, water and energy use.[5, 6] Considering the increasing importance of cities in economic prosperity, sustainability, and social equity, there is a need for transformation to more sustainable and compact development patterns with a growing population living in urban areas.[4, 7, 8]

1.1 More Sustainable Infrastructures for Urban Development

One strategy for developing more sustainable and compact cities is to adopt more sustainable infrastructure designs to reinvent the urban infrastructure system. Examples of more sustainable designs include low impact development (LID) and transit-oriented development (TOD). LID is an alternative green strategy for conventional stormwater management.[9, 10] LID strategies for stormwater management include bioretention facilities, rain gardens, vegetated rooftops, rain barrels, and permeable pavements. LID not only has the ability to control stormwater runoff, but also provides additional benefits including the creation of green space, a reduced heat island effect, improved air and water quality, and can be an important amenity that will increase walkability, livability and property value.[11, 12]

TOD is the creation of compact, walkable, mixed-use communities centered on high quality transit services.[13] It can provide a high quality of life and reduce automobile use as well as fuel consumption.[14] There are considerable discussions about the details of best TOD design practices.[15] However for the purposes of this dissertation, I simply rely on a minimum density of 15-units/acre at an unspecified walkable distance from an unspecified mode of public transit.[16]

These efforts aim to reshape the form of cities and create a more sustainable and resilient urban environment. However, many studies have only evaluated the local environmental-economic benefits of these efforts[12, 17, 18] at the community level. The broader impact on land use pattern and the built environment still needs to be understood. To fully understand the effect of these efforts in creating a more compact and sustainable urban environment, it is necessary to extend the scope of the analysis of how cities grow with respect to the adoption of LID and TOD, and to how the adoption contributes to a more comfortable, affordable and mobile environment.

1.2 Interdependence between Infrastructures and Socioeconomic Environment

From the perspective of complexity, cities are complex adaptive systems incorporating various economic, environmental and social interactions.[19] Infrastructures (e.g. buildings, transportation, water, power and waste) make up the underlying physical structures of cities. The growth of cities is driven by the interactions between physical structures and the socioeconomic environment. Infrastructures are the foundation for residence, business and mobility in the cities. Access to roads, water, sewer, and electricity are all essential to a sustained, rapid and sound socioeconomic development. As a feedback, economic growth and social harmony will continuously boost the improvement of infrastructure services to satisfy the increasing demand for mobility, clean water and air, livable communities, and so on. The dynamic interconnection shapes the growth of the city with emergent properties that reveals the quality of life in the city (Figure 1.1). Therefore, to effectively manage the sustainable development of cities, it is necessary to understand the dynamic interdependence between infrastructures and the socioeconomic environment.[20] The goal is to create more sustainable urban infrastructure systems by providing a combination of desirable features that can increase the adoption of more sustainable infrastructures.

Figure 1.1 Interdependency between infrastructure systems and the socioeconomic environment: the emergence of macro patterns (e.g., land use, quality of life and carbon footprint) driven by micro decision makings and interactions (e.g., housing location, commute to work, shopping and business location).

1.3 Preferences for More Sustainable Infrastructures and More Compact Living Spaces

One of the driving forces of the interdependence between infrastructures and the socioeconomic environment is the public's preference for, and choice of more sustainable infrastructure designs and more compact living spaces. Identification of individuals' preferences can reveal the market potential of more sustainable infrastructures and more compact communities. It can also allow urban planners and developers to understand the importance of design attributes to people with different socioeconomic characteristics. The associated willingness to pay for more sustainable infrastructures and more compact communities can influence policy making and investment. Green et al found increased willingness to pay (WTP) and a marked preference for larger and physically greener infrastructure developments in Manchester, UK.[21] Bowman et al found that residents in Ames, IA, US are willing to pay more for most LID features (e.g., rain gardens, open spaces, neighborhood streams) with the exception of clustered housing.[22] Higher WTP indicates a higher return on investments in LID for city managers and developers. Leinberger found that average rent in all the real estate products in established walkable communities in metro Atlanta is 112 percent higher on a rent-per-square-foot basis than drivable sub-urban real estate.[23] The higher return may stimulate the supply and market growth of investing LID and TOD.

1.4 Agent-based Modeling for Predicting the Adoption of More Sustainable Infrastructures and More Compact Living Spaces

Agent-based modeling is an approach suited to the study of ecological, social, and economic systems in which sustainability is of interest. Agent-based models (ABMs) allow convenient modeling of agents' adaptive decision-making and strategies, interactions between multiple agents, trading rules and market structure. ABMs predict the emergence of market patterns that can allow for the identification of tipping points (e.g., stock market crash), the prevention of unintended consequences (e.g., tragedy of public goods) and policy designs (e.g., a carbon trading market). ABMs have been developed to evaluate the cost-effectiveness of emerging market-based policy instruments and regulations. Previous studies include the application of ABMs to assess the impact of water pollution trading policy on chemical oxygen demand (COD) reduction in the river,[24] the efficiency of a water quality trading program in bilateral and clearinghouse markets,[25] the impact of an emission tax in the agricultural sector on greenhouse gas emission mitigation,[26] and the efficiency of several novel mechanisms in the Smart Grid market to manage the trading of electricity between the numerous active parties within the grid.[27] ABMs have also been developed to predict the adoption of green technologies in response to environmental change and policy intervention. Previous studies include the application of ABMs to measure the effect of technological innovation in speeding the adoption of eco-innovation alternative fuel vehicles,[28] and to predict the diffusion of water-saving innovations.[29]

1.5 Motivation and Scope of This Dissertation

This dissertation presents an integrated modeling and analysis framework based on the development of an agent-based model for the management of complexity in urban systems. This framework is used to the exploration of more sustainable development scenarios and the investigation of more sustainable infrastructure designs and responsible policies. Specific topics addressed in this work include:

1) Development of an ABM to predict the adoption of residential communities combining features of LID, TOD and more compact living spaces;
2) An investigation of different policies (i.e., impact fees, subsidy) for implementing LID to promote more compact living spaces, and evaluate the environmental-economic benefits of the emerging land use pattern;
3) Development of an individual choice analytic model based on existing survey data to calibrate agents' preferences;
4) Development of a survey to gather data for running the individual choice analytic model in order to predict the behavior of metro Atlanta residents choosing residential communities that combines features of LID, TOD and more compact living spaces; and
5) An evaluation of the market potential of LID and TOD in the metro Atlanta that sheds light on the implication for more compact development.

Chapter 2 describes the development of an ABM that predicts the land use pattern at the neighborhood scale. This ABM simulates several decision-making processes, including individuals' housing choices, the developer's investment choices, the government's infrastructure improvements, and drivers such as tax revenue and impact fees. The model simulates the development pattern of ten-acre "subdivision" increments. Homebuyers choose to purchase single-family houses or apartment homes. Each subdivision will receive stormwater runoff control investment to capture the first 1.5 inches of rain water over a 24 hour period and transportation improvement to reduce traffic cost. Model parameters are obtained from the existing literature and include consumer preferences, cost, and national market statistics. The model is validated by comparing the predicted house price with the existing hedonic price. In a given model run, agents act and interact according to model imposed rules, resulting in the emergent adoption curve of the two residence options and a land use pattern.

Chapter 3 describes the investigation of policies that promote the adoption of LID and more compact development. With the help of the ABM, a more sustainable development (MSD) scenario is developed that introduces an impact fee that developers must pay if they choose not to use LID (i.e., rainwater harvesting, porous pavement) to build houses or apartment homes. Model simulations show homeowners selecting apartment homes 60% of the time after 30 years of development in MSD. In contrast, only 35% homeowners selected apartment homes after 30 years of development in a business as usual (BAU) scenario where there is no impact fee for LID. The increased adoption of apartment homes results from the lower cost of using LID (i.e., rain gardens, native vegetation and porous pavements) in public spaces and improved quality of life for apartment homes relative to single-family homes. The MSD scenario also generates more tax revenues and water savings than does the BAU.

Chapter 4 describes the calibration of an individual community choice model, which is critical to the reliability of the ABM. With data from a 2011 National Association of Realtors community preference survey, a latent class choice model is applied. This modeling discovered four classes of individuals that reveal distinctive behaviors when choosing smart growth neighborhoods based on the interplay between aspects of community design, socioeconomic characteristics, and personal attitudes. Linking the results of the latent class choice model to an agent-based market diffusion model enables planners to evaluate the effectiveness of a proposed smart growth neighborhood design in inducing less sprawling development.

Chapter 5 describes the efforts in revealing the preferences of metro Atlanta residents for different community designs. A survey was developed that includes questions associated with choosing the best/worst community among 14 scenarios. With the responses collected on Mechanical Turk, a latent-class residential community choice model of four distinctive classes was developed to reveal heterogeneous preferences for community designs. The spatial distribution of the four classes was mapped out to visualize the locations of the demand for different community designs in metropolitan Atlanta. The analysis suggests that LID and TOD have a great potential for adoption in the metro Atlanta area, as the increase in housing price is found to have a weak negative impact on the adoption of LID and TOD. Further, I integrated the individual residential community choice simulation into an agent-based market diffusion model to predict the emergent land use pattern and explore the policy that can drive the adoption of more compact development. Results suggest that the current policy requiring single-family houses to implement LID based on individual sites should be switched to one that requires community-based LID for single-family houses. Such a policy switch will lead to a higher adoption of apartment homes with LID and TOD. Lastly, it is estimated that a 28% carbon emission reduction is possible from more compact development driven by LID and TOD.

Chapter 6 presents the conclusions based on the progress of this study. Future work is recommended in terms of the development of an integrated platform that support the integration of individual modules for modeling the complexity, big data analytic techniques for uncovering the governing interdependency between infrastructures and the socioeconomic development, and the exploration of sustainability metrics for public communication to build citizen capacity for sustainable cities.

CHAPTER 2

DEVELOPMENT OF AN AGENT-BASED MODEL TO PREDICT THE ADOPTION OF LOW-IMPACT, TRANSIT-ORIENTED AND MORE COMPACT COMMUNITIES

2.1 Introduction

Understanding of the interdependency of infrastructure investment and land development is difficult and limited because dynamic urban systems are complex.[19] Analysis of highly complex emergent growth patterns using statistical methodologies requires large amount of data and observations. As a result, agent-based models (ABM) that can account for heterogeneous and adaptive behaviors, information asymmetry, and uncertainty have been widely applied in artificial market simulations for complex adaptive systems such as housing markets, land and other markets.[30-32]

There are many limitations associated with ABMs to predict human behavior. First, one needs to select the appropriate utility functions or fuzzy rules that describe the agents' behavior.[33] Second, the ABM is always a simplification of the potential interactions that occur in the real world.[34, 35] Third, model parameterization and validation is a challenge requiring difficult or expense to obtain data on adoption rates against which to compare to model predictions.

In this study, I develop an ABM that predicts the development of Greenfield land for residential purposes. It should be noticed that redevelopment of brownfield would be the more sustainable choice but I simplified the case study for the purpose of making it more generic. The ABM simulates several decision-making processes, including individuals' house choices, the developer's investment choices, the government's infrastructure improvements, and policy drivers such as tax revenue and impact fees. The model simulates the development pattern of ten-acre "subdivision" increments (i.e., the minimum parcel size for development). Homebuyers choose to purchase single-family houses or apartment homes. Each subdivision will receive stormwater runoff control investment to capture the first 1.5 inches of rain water in a 24 hour period and a transportation improvement to reduce traffic cost. Model parameters are obtained from the existing literature and include consumer preferences, cost, and national market statistics. The model is validated by comparing the predicted house price with the existing hedonic price. In a given model run, agents act and interact according to a set of rules, resulting in the emergent adoption curve of the two residence options and a land use pattern.

2.2 Materials and Methods

The following subsections introduce the features of the ABM that incorporates the agents' behaviors (e.g., finding a house, improving infrastructure, and building properties) and interactions (e.g., tax payment, impact fees, house sale):

2.2.1 Study Areas and Agent Types

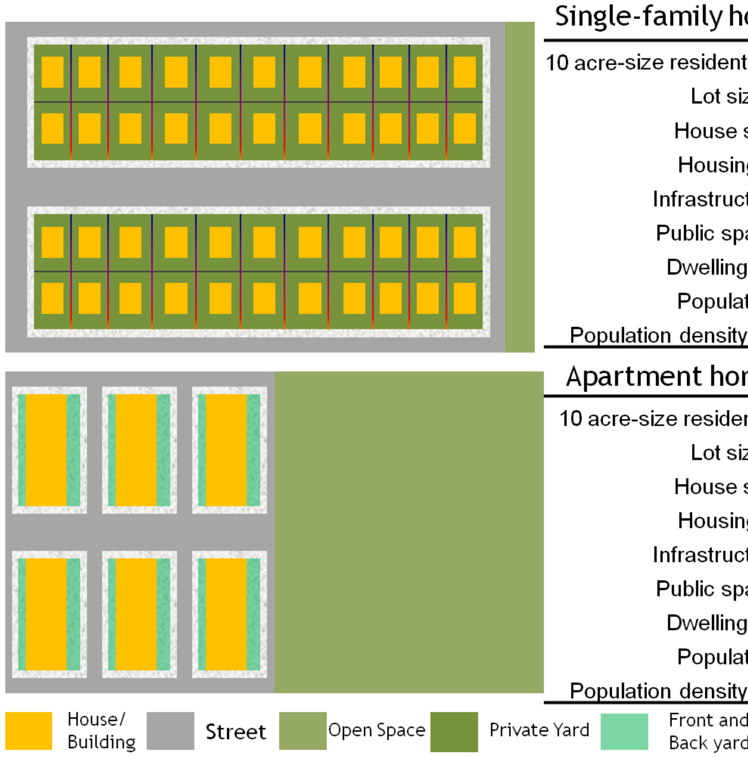
The study area is Greenfield land next to an urban area. The nine square miles are divided into 24 × 24 grid cells that contain ten-acre plots. A basic water supply, a sanitation sewer network, a storm water drainage system, and roads are prerequisites of the development and the local government uses funding from the federal and state governments to build these infrastructures (In fact, the question of who pays for the construction of the infrastructures is much more complex and variable). The additional infrastructures needed to control 1.5 inches of rainfall in 24 hours and to improve the public transportation system have to be paid for by homeowners, local government, and/or developer. I do not consider the impact of business growth on residential development; I assume all residences have equal access to businesses. Two residential subdivision types are developed: (1) single-family homes comprising a lower-density subdivision and (2) apartment buildings comprising a higher-density subdivision (Figure 2.1).

The state variables associated with each grid cell include: a suitability score (artificial values ranging from 0 to 10, which set up the sequence of parcel development), development status, subdivision type, storm water management type, amount of improved open space, traffic cost savings (the benefits from transportation improvements), property value, sale price, and number of vacant units.

The model simulates the interactions of three agents: one government agency, one developer, and homebuyers. The government provides infrastructure services and improvements. The government's objective is to raise tax revenue from new residents. The developer converts the undeveloped land into residential subdivisions to satisfy housing demand and sells the properties to homebuyers. The developer's objective is to make a profit on the sales. The homebuyer's objective is to purchase a residence. Bounded rationality is used to simulate home selection, which assumes limited information is available and that an individual cannot consider every possibility.[36]

Homebuyer's purchase choice under bounded rationality is influenced by the homebuyer's income, proportion of income spent on household expenses, transportation expenses, non-housing consumption utility, and living environment preference (open space, lot size, house size, and traffic cost saving).

The state variables associated with the developer agent are building construction cost (in dollars/ft^2), subdivision infrastructure cost per housing unit (cost per mile of roads approaching communities, subdivision grading cost, and cost of connecting subdivisions to water, sanitation and storm networks), and the ratio of soft cost (e.g., permits, advertisement) and profit to total construction and infrastructure costs. (The asking price includes the expected profit, permit fees, finance cost and construction cost.)



Single-family house

10 acre-size residential subdivision	
Lot size	7, 260 sq ft
House size	2,688 sq ft
Housing%	73.5%
Infrastructure%	23.6%
Public space%	2.9%
Dwelling unit	44
Population	110
Population density (person/acre)	11

Apartment home

10 acre-size residential subdivision	
Lot size	1,200 sq ft
House size	1,200 sq ft
Housing%	13.8%
Infrastructure%	22.9%
Public space%	63.3%
Dwelling unit	270
Population	675
Population density (person/acre)	67.5

Figure 2.1. Residential subdivision design: single-family house representing low-density development versus apartment home representing high-density development.

2.2.2 Design Concepts

2.2.2.1 Basic Principles. The undeveloped land is viewed as one district for residential development adjacent to the existing city. The configuration of jobs, schools, and other factors outside the studied area is fixed as the same exogenous forces for all subdivisions. The locations of businesses are assumed to have no impact on housing location within the same area.

Bounded rationality is used to simulate home selection. Individuals have bounded rationality because of limited information and an individual cannot consider every possibility.[36] The home developer is assumed to maximize profit. Competition between home developers is not considered, and one profit-maximizing developer represents the investment behavior.

2.2.2.2 Emergence. Choice of residence in apartment homes versus single-family houses as well as land use patterns emerges from the complex interactions among homebuyers, the developer, and the government. House price is another emergent property from the model and results from the house sale process. House price is the average deal price. The deal price of a house equals the highest bid price, which should exceed the asking price. I verified the model by comparing the simulated house price with the prices reported by hedonic price model studies.

2.2.2.3 Behaviors. Homebuyers know certain information about each house property, including lot size, house size, amount of improved open space and transportation cost savings. The increase in open space and traffic cost savings will be considered in decisions about willingness to pay (WTP) and in the probability of bidding. The developer will change the volume of new investment according to the changing demand for the two subdivisions types.

2.2.2.4 Objectives. Homebuyers aim to find a house that is affordable. The home developer aims to sell the houses to the buyers offering the highest bid prices to maximize profits.

2.2.2.5 Prediction. The developer determines the number of new apartments and single-family houses to be built for each period.

2.2.2.6 Interaction. Homebuyers, the developer, and the government interact via the housing market. Housing purchases occur between a homebuyer and the developer. A successful bid requires that a homebuyer offer the highest price among those who bid on a given property. Infrastructure improvement affects the desirability of a given home, and the government is limited in how much improvement it can achieve. In principle, the government is limited by the tax revenues that it can collect, assuming that the government wants to keep revenue and expenditure in balance.

2.2.3 Process Overview and Scheduling

The overall goal that drives land development and the interactions among agents is meeting the increasing demand for housing. One thousand prospective homebuyers are assumed to enter the housing market every year. The agent-based housing market model proceeds in annual time steps, and the simulation runs for 30 years. In the initial step (t = 0), we assume that half units are single-family houses and the other half units are apartment homes. The annual homebuyers are 1,000. Consequently, based on community designs in Figure 2.1, the developer builds out 616 single-family houses and 540 apartment homes, equivalent to 16 subdivisions in total. Homebuyers search for ideal properties to purchase and make the deals with the developer. This process generates initial residents, demand, and prices. In the next time step, the five modules of the model are run as described in the following order (Figure 2.2).

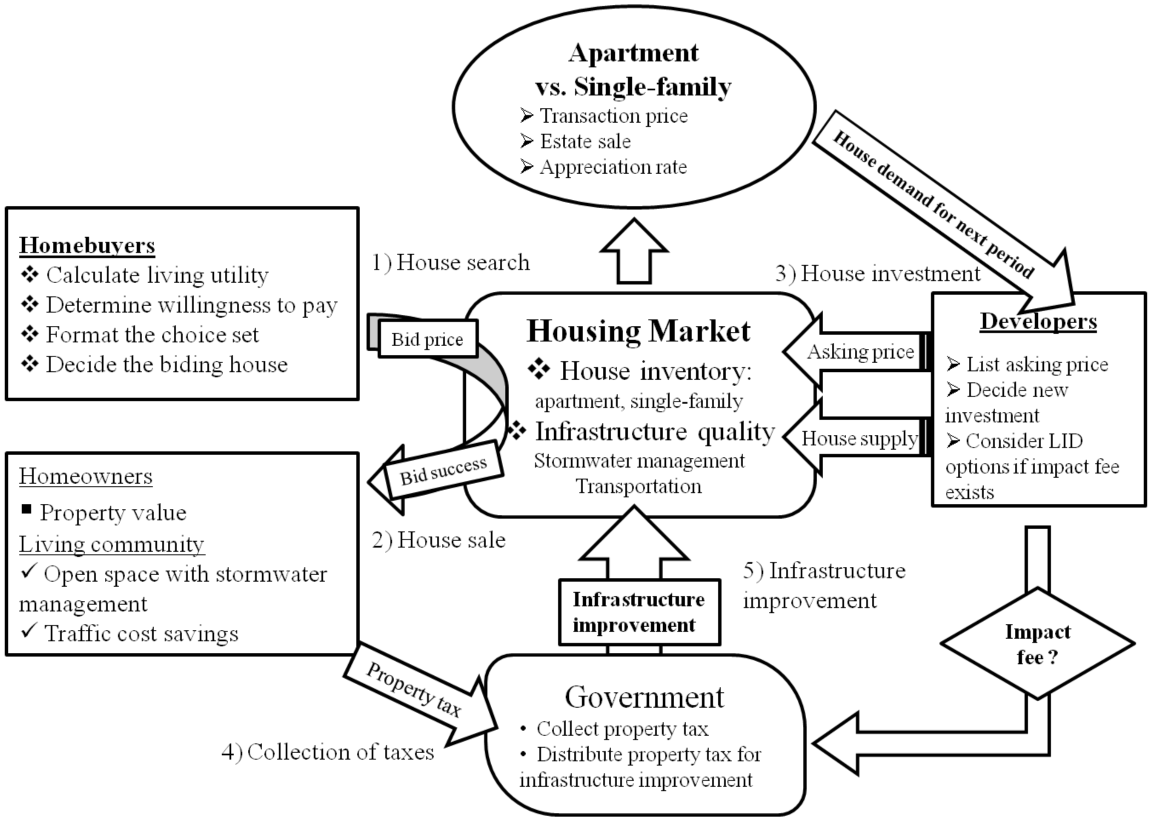


Figure 2.2. Flow chart for the agent-based housing marketing simulation with infrastructure improvements: 1) house search, 2) house sale, 3) house investment, 4) collection of taxes, and 5) infrastructure improvement.

2.2.3.1 Collection of Taxes to Support Infrastructure Improvement

The government's budget for storm water management is calculated at the start of the first year (t = 1), as the sum of the cost of maintaining the storm water control facilities plus the cost of installing the new facilities. In the first year, the government borrows money if property taxes (tax rate = 0.01) are insufficient to complete installation of storm water control facilities. In the following years, the government does not borrow money for new facilities and only tax revenues can fund new facilities. However, the property tax rate for storm water management cannot exceed 0.01 of the property value unless it cannot cover the maintenance and debt service cost. In such cases, it can exceed 0.01 of the property value. Also, the tax rate for storm water management can decrease when property taxes at the rate of 0.01 exceed the cost for storm water management (Eq. 2.1). (This ABM does not include any tax revenues for other important services like schools or public safety. If they were included, the tax savings from storm water management could be used to improve these services.) Transportation improvements starts at the beginning of the sixth year (t = 6) with a fixed tax rate of 0.01.

$$r = \begin{cases} \dfrac{TM + D}{\sum PV} & \text{if } \dfrac{TM + D}{\sum PV} > r_d \\ r_d & \text{if } \dfrac{TC + TM + D}{\sum PV} > r_d \\ \dfrac{TC + TM + D}{\sum PV} & \text{if } \dfrac{TC + TM + D}{\sum PV} < r_d \end{cases} , \tag{2.1}$$

where r is the estimated tax rate; r_d is the predefined tax rate; TC is the total required cost for infrastructure improvement; TM is the total maintenance cost; D is the annual debt charges over 20 years; and PV is the assessed house property value, which is equal to the sale price multiplied by 0.4.

<u>2.2.3.2 Infrastructure Improvement: Storm Water Management and Transportation Improvement</u>

Tax revenues collected from completed subdivisions are used by subdivisions of the same type for maintenance and improvement. Each subdivision, including the subdivisions that will be built in the current time period, receives the same funding from property taxes paid by current homeowners. If one subdivision needs less than it receives to fulfill improvement targets, the surplus will be shared among the other subdivisions.

The amount of improved open space and traffic cost savings are updated after each yearly investment.

The level of stormwater management implementation is defined by Eq. (2.2):

$$OS_{improved,t,j} = OS_{improved,t-1,j} + \frac{I_{storm,t,j}}{C_{storm}} , \tag{2.2}$$

where $OS_{improved,t,j}$ is the size of the area of improved open space with stormwater management in subdivision j at time t; $OS_{improved,t-1,j}$ is the size of the area of improved open space with stormwater management in subdivision j at time t – 1; $I_{storm,t,j}$ is the amount of investment in stormwater management in subdivision j at time t – 1; and C_{storm} is the cost per square foot for the implemented technologies and subdivision types (see Appendix Stormwater Management Techniques). The maximum amount of improved area equals the total available public open space.

The other infrastructure investment is transportation improvement, which aims to provide connectivity between the study area and other urban areas. The return on transportation improvements received by households is defined as traffic cost savings in Eq. (2.3);

$$TCS_{j,t} = TCS_{j,t-1} \times (1 - D_{tcs}) + \frac{TI_{j,t}}{N_j} \times R_j , \tag{2.3}$$

where $TCS_{j,\,t}$ is the traffic cost savings when living in subdivision j at time t; $TCS_{j,\,t-1}$ is traffic cost savings from living in subdivision j at time t – 1; D_{tcs} is the depreciation rate of the savings, assigned with the value 0.2 (based on depreciating infrastructure); $TI_{j,t}$ is the investment volume; N_j is the number of house units in subdivision j; and R_j is the return in transportation cost savings for every dollar in transportation improvement for subdivision j. Considering the empirical correlation between housing density and the return on investment,[5, 6] R_j is 10 cents for a single-family home and 30 cents for an apartment home.[7]

2.2.3.3 Developer Decision Making: Building Apartments and Houses to Meet the Current Year's Demand

The developer builds new apartments and single-family houses to satisfy the demand built for the current year. The demand for new houses (or the number of new homes that are built) is the difference between the number of bids and the inventory. The asking price and the minimum annual payment for apartment homes and single-family houses are given in Eqs.2.4 and 2.5.

$$P = (C_h + C_{in}) \times (1 + \eta), \tag{2.4}$$

where P is the floor price to sell, or asking price; C_h is building construction cost; C_{in} is subdivision infrastructure cost (e.g., cost per mile of roads approaching subdivisions, subdivision grading cost, cost of connecting subdivisions to water, sanitation and storm networks); η is the ratio of soft cost (e.g. financing cost, permit fees) and minimal profit to hard cost ($C_h + C_{in}$).

$$AP_k = P_k \times PR, \tag{2.5}$$

where AP_k is the annual payment (or the incoming cash flow from an investor's perspective) of house k; P_k is the floor price of house k; and PR is the annual payment rate of house k. Payment rate is based on zero down payments (i.e., the loan amount equals asking price). The PR of apartment homes (PR_{ap}) is 8%, which equals capitalization rate of apartment properties. PR of single-family houses (PR_{sf}) is 4%, which approximately equals 30-year fixed mortgage interest rates in single-family housing market.

2.2.3.4 House Search: Finding a House

Each of the 1,000 homebuyers examines 10 homes for potential purchase. The annual willingness to pay (WTP, Eq. 2.6) divided by pay rate is the bid price of homebuyers.[30, 37] If the bid price for a particular house is higher than the asking price set by the developer, the homebuyer will put the option into their choice set until the candidate house number reaches the search capacity. In the model, each homebuyer cannot visit over ten houses.

$$WTP_{i,j} = (I_i \times E - TC_i - Tax_j - M_j) \times \frac{U_{i,j}^2}{U_{i,j}^2 + B_i^2} \quad , \tag{2.6}$$

where $WTP_{i,j}$ is the WTP of homebuyer i for a house in subdivision j; I_i is the annual income of homebuyer i; E is expenditure as a proportion of income; TC_i is the traffic cost of homebuyer i; Tax_j is the expected property tax, which is equal to 40% of the asking price multiplied by the tax rate; M_j is the maintenance fee per unit in subdivision j; $U_{i,j}$ is the utility of homebuyer i in a house in the subdivision j (Eq. 2.7); and B_i is the unitless utility of non-housing expenditure of homebuyer i.

$$\begin{aligned} U_{i,j} = {} & \gamma_{i,LS} \times \log(LS_j) + \gamma_{i,HS} \times \log(HS_j) \\ & + \gamma_{i,OS} \times \log(OS_j) + \gamma_{i,TCS} \times \log(TCS_j) \quad , \end{aligned} \tag{2.7}$$

where $U_{i,j}$ is the unitless utility of homebuyer i for a house in subdivision j; LS_j is the lot size (ft^2); HS_j is the house size (ft^2); OS_j is improved open space (ft^2); TCS_j is traffic cost saving ($/yr); and γ weights the influence of these attributes in the homebuyer's personal utility perception, which is derived from individual preferences.

Once the choice set is formed, the homebuyer selects one house to bid on. The logistic model in Eq. 2.8 is used to simulate the decision process. All the options are listed in a sequence with a corresponding probability interval for each option; these intervals collectively span from 0 to 1. Then the random number generator produces a number between 0 and 1. The homebuyer chooses the property with the probability interval into which this randomly generated number falls.

$$P(choice = j) = \frac{e(U_{i,j})}{\sum e(U_{i,j})} \tag{2.8}$$

2.2.3.4.1 Parameterization of preference.

The homebuyer's WTP is given by Eq. 6. The term $\frac{U_{i,j}^2}{U_{i,j}^2 + B_i^2}$ is set to the ratio of housing expenditure to total expenditure excluding transportation ($R_{housing}$) and equals 0.38 for households with annual income equals \$70,000.[38, 39] B_i and U_i measure the household's expectations regarding non-housing and housing consumption. B_i is the unitless utility of non-housing expenditure with a base value of 3.5. Accordingly, the base value for U_i is 2.74. B_i is updated according to the income elasticity of non-housing demand. U_i remains constant regardless of household income.[40] Thus, $R_{housing}$ decreases as income increases.[39]

U_i can positively affect the weight of house attributes per Eq. (9), which can result in an increased difference in the perceived utilities of living in two different houses (Eq. 2.6). It results in a higher probability of choosing the house with larger utility (Eq. 2.8). Preferences are defined as the marginal WTP for an additional amount of house attributes in Eq. 2.9. Based on Eq. 2.9, the weights γ of house size, lot size and open space in decisions are summarized in Table 2.1. To represent taste heterogeneity, the weights γ are normally distributed with variances equal to 5% of the means.

$$\frac{\dfrac{\partial WTP_{i,j}}{WTP_{i,j}}}{\dfrac{\partial X_{j,k}}{X_{j,k}}} = \frac{2U_{i,j}^{-1}B_i^2}{U_{i,j}^2 + B_i^2} \times \gamma_{i,k} \tag{2.9}$$

Calculation of the weight for traffic convenience measured by traffic cost saving is different from the weight of open space because of the limited empirical studies about elasticity of housing demand to transportation convenience. Treating the savings in transportation expenditures as part of income, the first derivative of elasticity of housing demand to traffic cost savings equals the ratio of housing expenditure to total expenditure multiplied by expenditure as a proportion of household income (see Table 2.1). To simplify, the transportation cost and property tax terms in Eq. (2.6) are replaced by particular percentages of income, 10.2% for transportation cost and 2.7% for property tax, according to a 2010 household consumption expenditure survey.[38] The maintenance cost remains constant, and the average savings are assumed to reach 40% of the transportation cost before the improvement. The traffic cost savings target represents the potential quality of traffic conditions with proper investment, and its impact on apartment adoption was investigated through sensitivity analysis. In this model, I find that the weight of transportation cost saving equal to 0.11.

The combination of Eq. 2.6 and 2.8 to predict house type choice probability and the associated WTP can be validated though Eq. 2.10. The calculated income elasticity of housing demand is 0.55, which is close to the value of 0.54 found in other reports.[41]

$$\frac{\frac{\partial WTP_{i,j}}{WTP_{i,j}}}{\frac{\partial I_i}{I_i}} \approx 1 - \frac{2B_i^2}{(U_{i,j}^2 + B_i^2)} \times \frac{\frac{dB_i}{B_i}}{\frac{dI_i}{I_i}} \tag{2.10}$$

Table 2.1. Elasticity of housing demand to a series of attributes and the corresponding weights of these attributes in utility (Eq. 2.7).

Term	Value	γ	Source
Elasticity of housing demand for house size	0.245	0.54	[42-44]
Elasticity of housing demand for lot size	0.065	0.14	[42-44]
Elasticity of housing demand for open space	0.0045	0.01	[42, 44, 45]
First derivative of housing demand for traffic cost savings	0.247	0.11	[38]
Income elasticity of housing demand	0.54	NA	[46]
Income elasticity of non-housing demand	0.36	NA	[41]

2.2.3.5 House Sale Process

The developer sells properties to the homebuyers offering the highest WTP for each property, which must exceed the minimal annual payment. The process results in the appreciation of prices that is used to update property values of the sold houses.

2.2.3.6 House Investment: Building Apartments and Houses to Meet the Current Year's Demand

To be successful, it is critical for the developer to predict with some accuracy the demand for apartment homes and single-family houses during the next time step. In each simulated time step, 1,000 homebuyers drawn from a distribution of socioeconomic characteristics are assumed to want to buy a home in the studied area. The projected demand for apartment homes and single-family houses in the next time step equals the recorded demand in the current phase via Eq. 2.11:

$$D_{t+1} = D_t, \tag{2.11}$$

where D_{t+1} is the estimated demand in the next time step and D_t is the number of homebuyers bidding on apartments or single-family houses in the current house-selling step.

The numbers of apartment homes and single-family houses to be constructed are determined by the difference between the estimated demand in the next time step and the house inventory at the end of the current period via Eq. 2.12:

$$Invest_{t+1} = D_{t+1} - Inventory_t \,, \tag{2.12}$$

where $Invest_{t+1}$ is the number of single-family houses or apartment homes to be constructed; D_{t+1} is the estimated demand for the next time step; and $Inventory_t$ is the inventory at the end of the current period.

2.2.3.7 Model Initialization

The initial state of the model world has 1,000 prospective homebuyers. The state and macroeconomic environmental variables are listed in Table 2.2. The initialization varied for each simulation within the same probability distribution of input parameters. The initial numbers of each of the two types of subdivisions (apartments and single-family homes) are estimated according to the aggregate living utility and affordability for the 1,000 homebuyers. The probability of choosing one subdivision type is determined by the average utility of each of the two subdivisions per Eq. (8), and total investment in one subdivision type equals the estimated probability times the total number of economically capable homebuyers whose bid price exceeds the asking price.

2.2.3.8 Simulation Platform

The agent-based model was built in NetLogo (http://ccl.northwestern.edu/netlogo/), a platform for simulating spatial logic driven by a multi-agent system and using a cellular automata approach. NetLogo is intended to model a range of phenomena, specifically complex systems with many interacting agents. A standard NetLogo model consists of a world with a set of agents and a suite of procedures specifying how the parcels and agents act and interact.[32]

Table 2.2. Model parameterization.

Entity	Variable	Definition	Value	Source
Homebuyers	I_i	Household income, $/yr	70,000 + 50,000 $\times$ Exponential distribution (λ = 0.9)	[47]
	E	Proportion of total expenditure on housing, traffic, food, etc	0.65	[38]
	$TransC_i$	Traffic cost	$TransC_i = -5\times10^{-7}\times I_i^2 + 0.157\times I_i + 916.0$ (R^2=0.992)	[39]
	B_i	The unitless utility of non-housing consumption	Normal (3.5 + $\lambda_B \times I_i$/70,000, 0.2) λ_B=0.36, Income elasticity of B_i	[41]
	$\gamma_{i,\,LS}$	Weight for lot size, measuring the attitude on lot size	Normal (0.14, 0.007)	Eq. 2.9
	$\gamma_{i,\,HS}$	Weight for house size, measuring the attitude on house size	Normal (0.54, 0.024)	Eq. 2.9
	$\gamma_{i,\,OS}$	Weight for open space, measuring the attitude on open size	Normal (0.01, 0.0005)	Eq. 2.9
	$\gamma_{i,\,TCS}$	Weight for traffic cost savings, measuring the attitude on traffic cost savings	Normal (0.11, 0.0055)	Eq. 2.9
The Developer	C_h	Building construction cost ($/ft^2)	82	[48]
	C_{in}	Infrastructure cost ($/unit)	$9,586 (single-family subdivision) $1,516 (apartment subdivision)	[49]
	η	The ratio of soft cost and profit to hard cost	26.3%	[48]
The Government	$r_{d,storm}$	The upper limit of tax rate for storm water management ($/$)	0.01	Model input
	$r_{d,traffic}$	The upper limit of tax rate for transportation improvement ($/$)	0.01	Model input
Macro Environment	N	Household immigration per year	1,000	Model input
	PR	Payment rate ($/$/yr)	0.04 (single-family house) 0.08 (apartment home)	[50, 51]
	$R_{traffic}$	Return on investment for transportation	0.1 (single-family subdivision) 0.3 (apartment subdivision)	13

improvement ($/$/yr)	

2.3 Results

I first employ the ABM to develop a business as usual (BAU) scenario, in which the government invests conventional storm water control management (CSM) (i.e., detention tanks) in each subdivision.

2.3.1 Model Validation

In this study, I use a pattern-oriented calibration and validation process.[52] The pattern-oriented model design assigns values to parameters on the basis of observed patterns in the agents. The emergent properties are compared with the observations to validate the ABM. Data for the parameters was collected from the existing literature on preferences, construction cost and market statistics (Table 2.2). Then I compare the emergent housing price from the market trade with existing hedonic studies on house price to validate the model. I also discuss consistence of the observed adoption with previous findings in the next section.

House price emerges from the interactions among homebuyers, the developer and local government through the housing market. In the BAU scenario, the price in the starting year (t = 0) is approximately $348,156 per single-family house and $149,664 per apartment home. These starting values are close to the hedonic house prices estimated using a tool developed by the National Association of Home Builders ($336,270 per single-family house and $144,262 per apartment home).[53, 54] The house price increases because of the promotion of storm water management and transportation improvements. For example, by the fifth year, the single-family house value rose by 4.56% with CSM, whereas the apartment home value rose by 6.07% with CSM (Figure 3). The appreciation of house and apartment prices that result from increased open space and storm water management is consistent with empirical studies, which have found values ranging from 2.7% to 15%.[9, 18, 45, 55] The consistency with literature values of house price and appreciated value indicates that the ABM structure and parameters are reasonable.

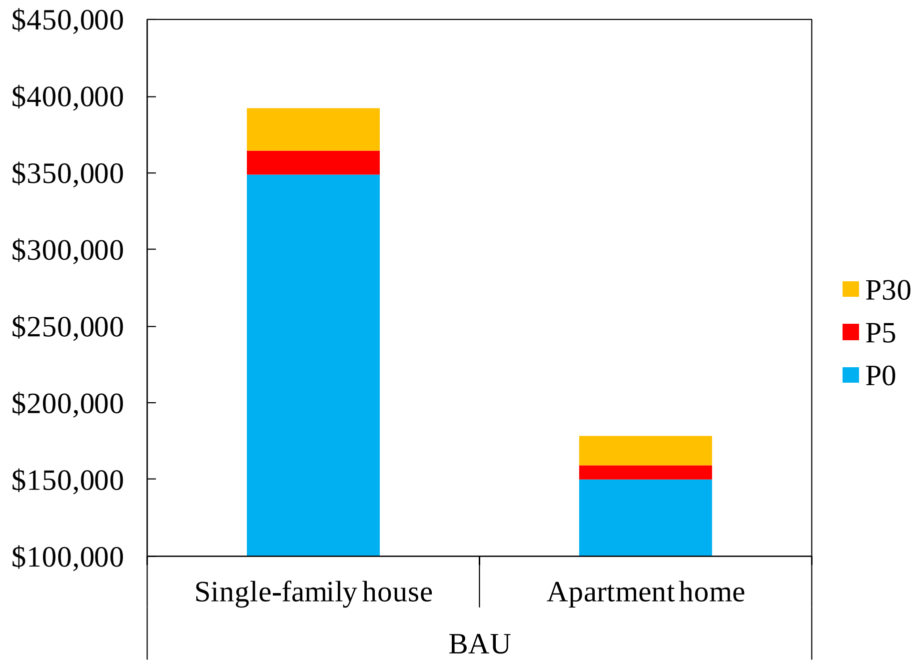


Figure 2.3. Mean house property value of a single-family house and an apartment home in the starting year, fifth year and thirtieth year under the BAU. The blue part of the column is the initial house price, the red part of the column is the added property value due to the first five years of storm water management, and the green part of the column is the added property value due to the next twenty-five-years of both storm water management and transportation improvements.

2.3.2 Adoption of Apartment Homes

The incentives resulting from infrastructure improvements (e.g. increased open space, traffic cost savings) can affect homebuyers' choices. In the BAU scenario, single-family subdivisions are the dominant design type. After 30 years, 64.8% and 35.2% of built properties are single-family houses and apartment homes (Figure 2.4a), respectively.

CSM is not particularly valuable to homebuyers choosing apartments or to the developer building apartments. Even when transportation improvements are introduced later, apartments remain less attractive to homebuyers and to the developer than single-family houses. The BAU scenario captures the reality that the conventional design and infrastructure improvement makes single-family houses more popular (see Figure 2.4b).

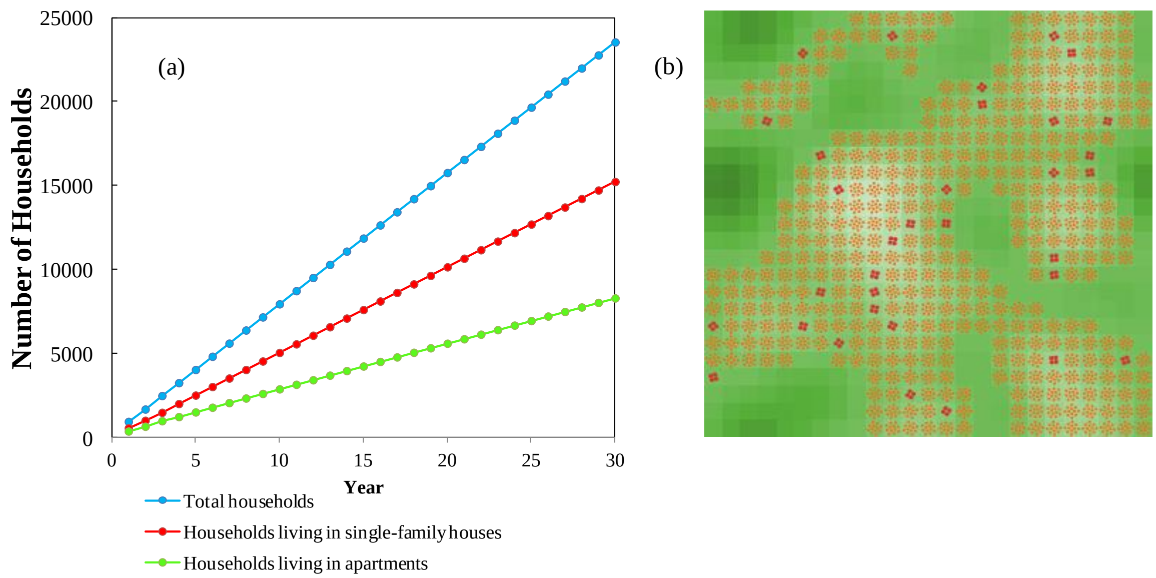


Figure 2.4. Household allocation between the two types of residential communities in the BAU: (a) the adoption in 30 years; (b) land use pattern in 30th year.

2.3.3 Application of the ABM to Investigate More Sustainable Development

In Chapter 3 I will employ the ABM to investigate strategies to increase LID adoption and evaluate the potential of LID to promote more compact development.

CHAPTER 3

POLICY DESIGN FOR PROMOTING LOW-IMPACT DEVELOPMENT AND EVALUATION OF SUSTAINABILITY IMPROVEMENT

3.1 Introduction

Low-impact development (LID) is a sustainable solution for storm water management that seeks to maintain the natural hydrologic characteristics of the site. LID differs from conventional storm water management (CSM), which uses drainage systems and detention tanks, as it includes the following infrastructures: (1) porous pavement, (2) creation of more open space (preserved native vegetation), (3) rainwater harvesting, (4) green roofs, (5) blue belts (retention ponds and infiltration basins), (6) reduced hardscape, and (7) grassy swales and wetlands for treating storm water.[56, 57] In this study, I employed all the above options except green roofs for storm water management. The green space created by LID has additional benefits, such as reduced heat effects and improved air quality, recreational opportunities, and other amenities.[11] Presently, the U.S. EPA recommends the application of LID in coordination with smart growth principles to limit the conversion of land cover and preserve open space.[58] Based on the data for Atlanta, an average apartment home and an average single family house requires 79 and 91 gallons of water per capita a day,[59] and 12.6 and 28.3 kWh of energy per capita a day,[60] and 200 and 1,350 square feet of land area for housing, respectively. Also apartments provide higher passenger volume that makes public transportation more cost-effective and contribute to walkability, which can reduce the traffic volume.[13] If LID can effectively increase the adoption of apartment homes, the development will be more sustainable than a conventional sprawling pattern.

Previous LID studies focused mainly on storm water runoff control efficacy,[17, 61, 62] environmental improvement [63] and economic advantages [11, 64] at the individual subdivision level. The feasibility of implementing LID to increase apartment home adoption (AHA) has not been investigated. Meanwhile, although LID has been shown to be an effective strategy, it has not been widely adopted, due to a lack of effective regulations and incentives that can drive the adoption of LID.[65, 66] In this study, I propose two policies, an impact fee and a subsidy, to promote the implementation of LID. In the case of the impact fee, if developers build projects that do not use LID practices they must pay impact fees that will allow local government to fully employ LID for public space and homeowner properties to control storm water. In the subsidy case, the government uses property tax to invest in LID. The ABM described in Chapter 2 is used to predict the adoption rate of LID and apartment homes in response to fees and subsidy. I also predict the adoption rate of apartment homes in response to fees charged in support of CSM fund. In this instance, the developer needs to pay an impact fee to support CSM investment. The goal is to determine whether the impact fee or LID contributes more to the higher adoption of more compact development.

3.2 Materials and Methods

3.2.1 Impact Fee

LID in public spaces is financed by local government. Public LID is an improvement of green space, which includes rain gardens, tree filter boxes, vegetated infiltration basins, and native plants. Public LID reduces the fiscal burden for local government and homeowners (who pay property taxes) because more costly CSM is not needed (Figure 3.1). LID for homeowner is an improvement of private properties, which includes permeable surfaces, rain barrels, and roadside swales (see Appendix A on Storm Water Management Technique). However, the developer does not automatically use homeowner-benefitting LID because of the higher construction cost involved (Figure 3.1). Therefore, an impact fee is proposed such that the developer must choose between adopting homeowner LID and paying impact fees. If the developer does not use homeowner LID, the government can use impact fees to pay the incremental cost of using LID (e.g., permeable surface, rain barrels, and roadside swales). Based on the cost information in Table A1, the impact fee is set to $13,000 per unit for single-family subdivisions and $1,500 per unit for apartment subdivisions to capture 90% of additional cost. Considering that the cost of using LID is less than the impact fee, the option of the developer chooses to adopt homeowner LID is modeled (Figure 3.1).

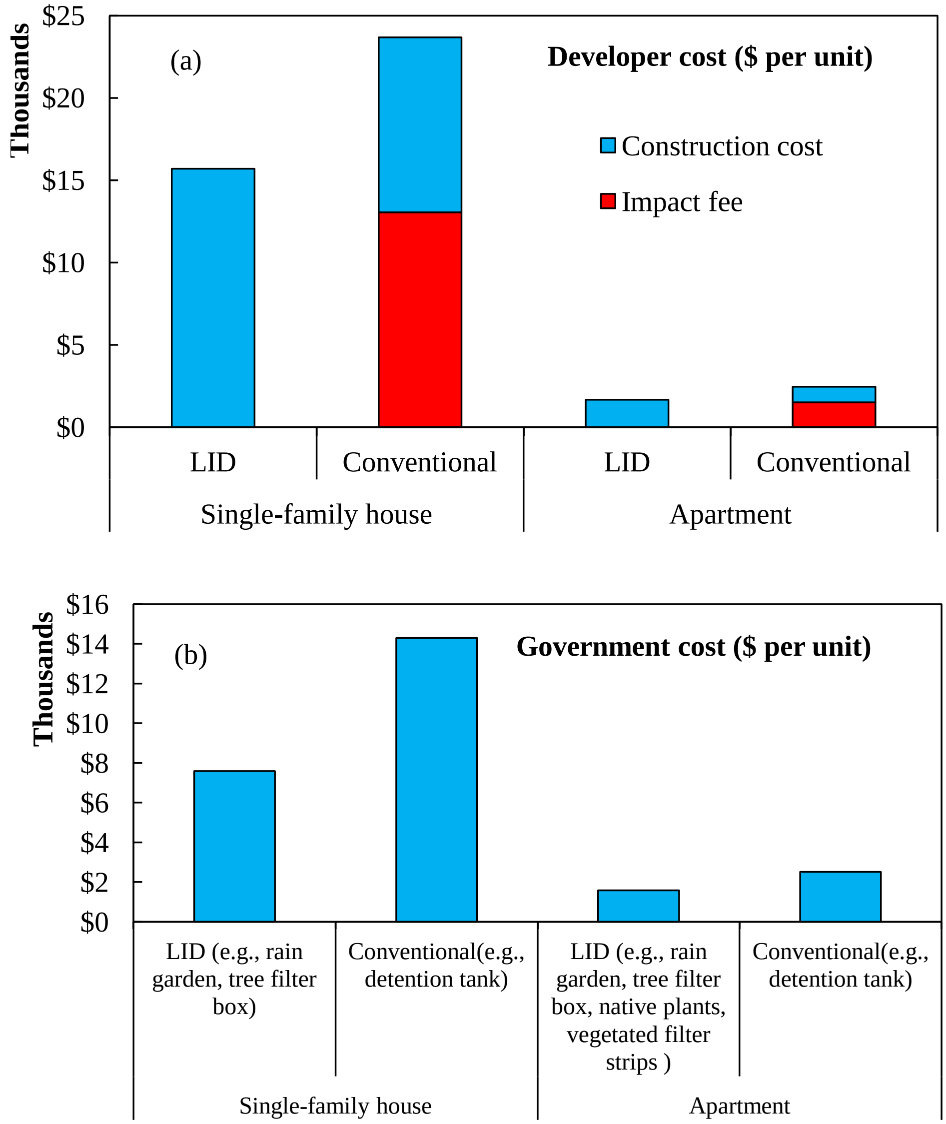


Figure 3.1. (a) The impact fee serves as an incentive for the home developer to use LID (e.g., permeable pavement, rain cisterns/barrels, and roadside swales) instead of the conventional approach (e.g., impermeable pavement, curbs, and gutters). (b) The cost to the government is lower for LID than for the conventional solution.

The developer uses its monopoly power to add the impact fee instead of the incremental cost of using LID, because the developer has monopoly power to pick the asking price for LID.

$$P = (C_h + C_{in}) \times (1 + \eta) + IF, \tag{3.1}$$

where P is the floor price to sell, or asking price; C_h is building construction cost; C_{in} is subdivision infrastructure cost (e.g., cost per mile of roads approaching communities, subdivision grading cost, cost of connecting subdivisions to water, sanitation and storm networks); the sum of C_h and C_{in} is hard cost; η is the ratio of soft cost (e.g. financing cost, permit fees) and minimal profit to hard cost; IF is the impact fee.

3.2.2 Subsidy

In this scenario, the local government pays for both the homeowner and public LID using tax revenues.

3.2.3 Preference for LID Features

In Eq. 2.9, the weight placed on open space is related to the associated design. In LID, recreation, amenities and aesthetics are improved owing to the general increase in vegetated and treed acreage.[11] These benefits are not anticipated under CSM using underground detention tanks. However, the amount of improvement varies with different subdivision designs. The improvement is less significant for a single-family house with a relatively large private yard than for an apartment.[45] In the model, a 20% increase with a 6% variance of the weight of open space is normally distributed among homebuyers for LID-oriented storm water management in single-family subdivisions. The increase for apartment subdivisions also follows the normal distribution of the N (3.2, 0.16) according to a study conducted in Philadelphia.[11] The weight on open space with LID design follows the normal product distribution.

3.3 Results

3.3.1 Adoption of Apartment Homes

By introducing impact fees to incentivize the adoption of LID, model simulation shows a transition from lower- to higher-density land use. After 30 years, 58.7% of the built properties are apartment homes (Figure 3.2b). The developed area is 25% smaller than that in the BAU scenario. The more expensive apartments relative to BAU do not adversely affect the choice of living in an apartment because buyer's willingness to pay is increased as a result of more valuable open space and reduced transportation costs. The predominance of inexpensive apartment homes (relative to single-family houses) also improves overall housing affordability. As a result, the model predicts that the total number of households in the development increases by 4% as compared with BAU.

Figure 3.2c shows the case where the LID fee is collected but LID is not implemented. Accordingly Figure 6c displays the impact of the fee collection but without the utility improvement that occurs with the implementation of LID. As shown in Figure 3.2c as compared to 3.2a, there is a slight increase in AHA. This observation is consistent with the finding that using an impact fee to fund CSM does not significantly affect the construction of single-family houses.[67] (CSM is an infrastructure that homeowners cannot see and does not provide the same utility as LID.) Impact fees make single-family houses relatively more expensive than apartment homes, which results in a slight increase in the AHA. But the increase in prices does not improve the quality of life (e.g., green space and traffic cost savings) for apartment owners since LID is not employed. Consequently, the AHA is not increased that much.

Next I look at the case where the local government pays for both homeowner and public LID using tax revenues, and compare it to the scenario where the developer pays for homeowner LID in MSD. Figure 3.2d displays the case where the local government pays for homeowner and public LID. As shown in Figure 3.2d as compared to 3.2b, there is a higher AHA when the developer pays for homeowner LID by imposing the impact fee. The increase in AHA is because using LID increases the quality of life of apartment owners more than that of single-family houses and the government has more money for public LID and transportation improvement by imposing impact fees for homeowner LID to the developer.

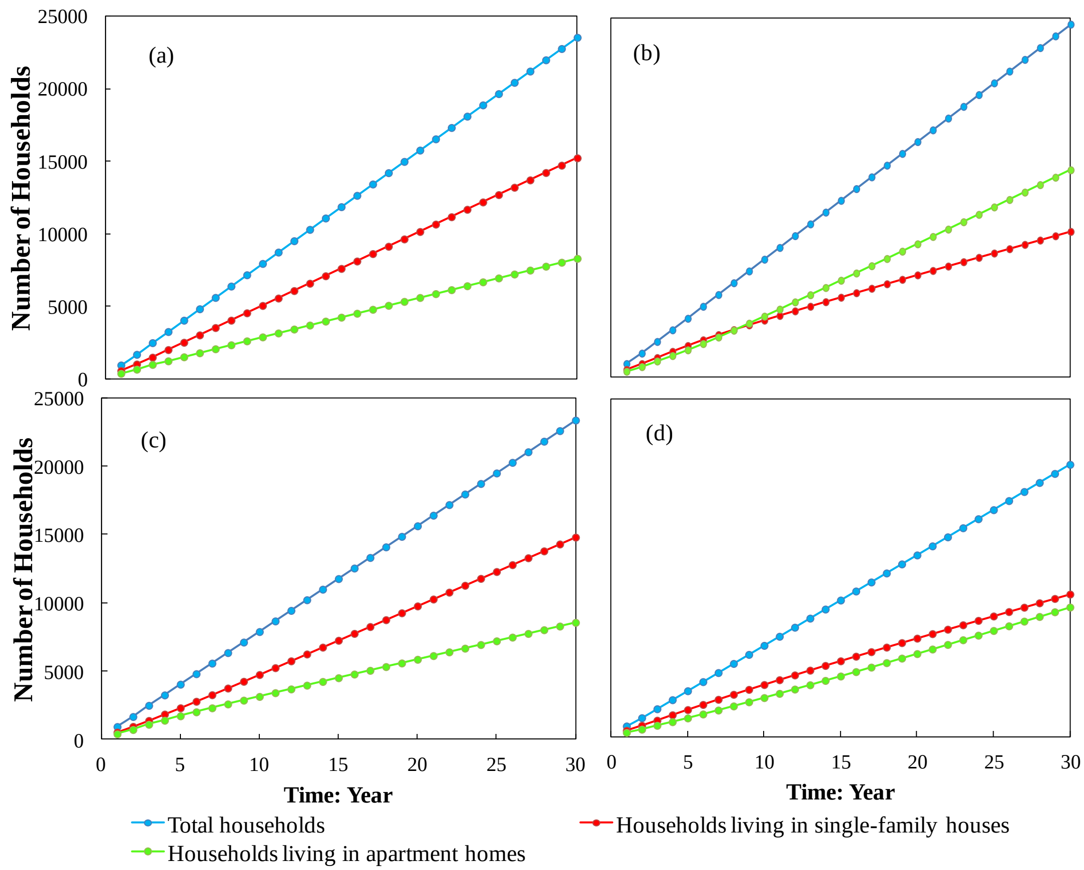


Figure 3.2. Household allocation between the two types of residential subdivisions: (a) business as usual (BAU); (b) impact fees serve as an incentive for the developer to implement LID; (c) the developer builds properties conventionally and pays the impact

fee designed to fund CSM; (d) the government pays for the costs of both homeowner and public LID.

Overall, I found the highest adoption of more compact development by imposing the impact fee to incentivize the implementation of LID. I defined this scenario as “More Sustainable Development (MSD)”.

3.3.2 Factors that Drives the Adoption of Apartment Homes in the MSD Scenario

Factors including buyer’s willingness to pay for LID, tax rate, and amount of property tax revenues are the major drivers of the shift from single-family house- to apartment home- dominated market development. As shown in Figure 3.2b, the AHA is less than that for single family homes for years 1 to 8. This trend can be understood by examining the economic flows that are used to pay for public LID. During these years the tax revenue is insufficient to pay for public LID. As a result, the quality of life for apartment owners does not increase as much as it does for later years when there is sufficient money to pay for public LID. In addition, taxes are higher during those years and apartment buyers’ willingness to pay is reduced. After year 8, there is sufficient tax revenue for public LID and the tax rate for apartment owners is smaller, which, in turn increases AHA, because public and homeowner LID will be fully deployed and this increases the apartment owners’ quality of life. In addition, taxes are lower in subsequent years and apartment buyers’ willingness to pay is increased. Transportation improvement begins in year 6 and this also improves the quality of life.

Another factor contributing to the shift is that fees must be paid by the developer if it does not implement homeowner LID. It turns out that it is more profitable for the developer to implement homeowner LID than pay the fees because adoption costs are lower than non-adoption’s impacts on government infrastructure costs. The cost for homeowner LID for single family homes is more than apartment homes. Also, the government's cost for public LID is less for apartment homes and apartment owners provide more tax revenues than single-family house owners. At year 8, single-family houses still face a shortfall of tax revenues to pay for public LID. Consequently, public LID is implemented later and the tax rate remains higher until the funds for public LID development are collected. On the other hand, apartment homeowners provide enough tax revenue to pay for public LID and it is immediately implemented and the tax rate is lower for future homeowners. As a result, the quality of life and willingness to pay increase faster for apartment homeowners than that for single-family houses. Therefore, buyers have a higher willingness to pay o choose apartment homes than single family homes.

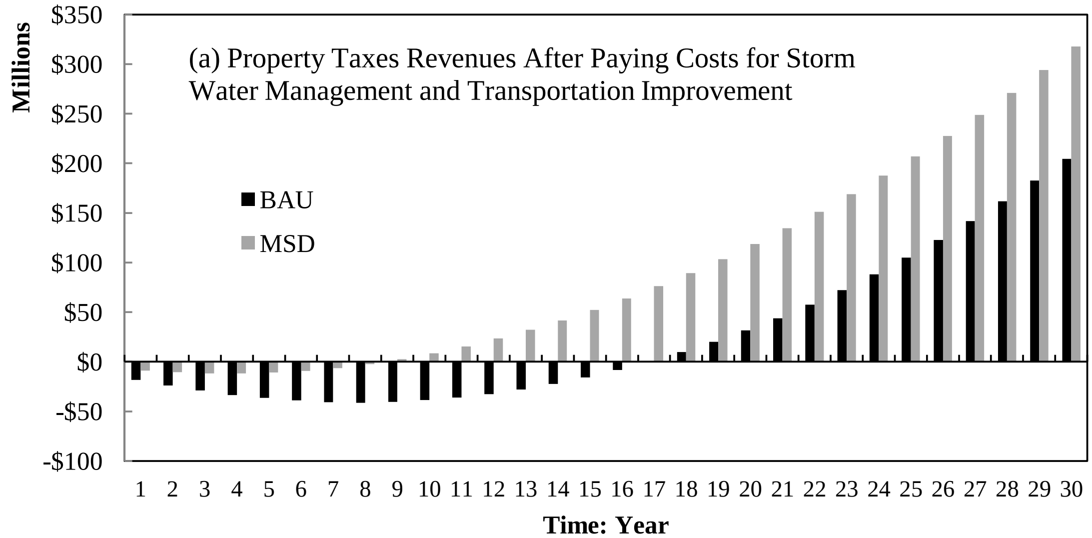
3.3.3 Economic-Environmental Impacts

3.3.3.1 Property Tax Revenues.

Given a fixed rate at 0.01 before year 6 and 0.02 after year 6, the accumulated tax revenues minus the accumulated cost for storm water management and transportation improvement are shown in Figure 3.3a. The net tax revenues in MSD are 55.4% higher than in BAU for 9 mi^2 after 30 years. More property tax revenues will allow for more infrastructure improvements in infrastructure as schools, public safety, etc. Also the average traffic cost savings per household in MSD increases by 12% as compared with BAU after 30 years. Overall, I observe a more prosperous real estate market in the MSD scenario than in BAU, which is suggestive of the effectiveness of LID and impact fee policy.

3.3.3.2 Rainwater Harvesting and Water Savings.

The average water demand per capita per year is 31,310 gallons in BAU and 28,886 gallons in MSD. Meanwhile, Rainwater runoff collected from rooftops, pervious landscape, and green space can supply part of local water demand. Water supply from a central water plant is reduced by 41.5% in MSD owing to the rainwater harvesting (Figure 3.3b). More importantly, the operation (and capital) cost for water supplied by the central water plant are expected to decrease in MSD because of the more compact land use and shorter transport distances within the developed area. However, these rain data pertain to Atlanta as an example, and thus the rainwater harvesting conclusions cannot necessarily be generalized to all cities.



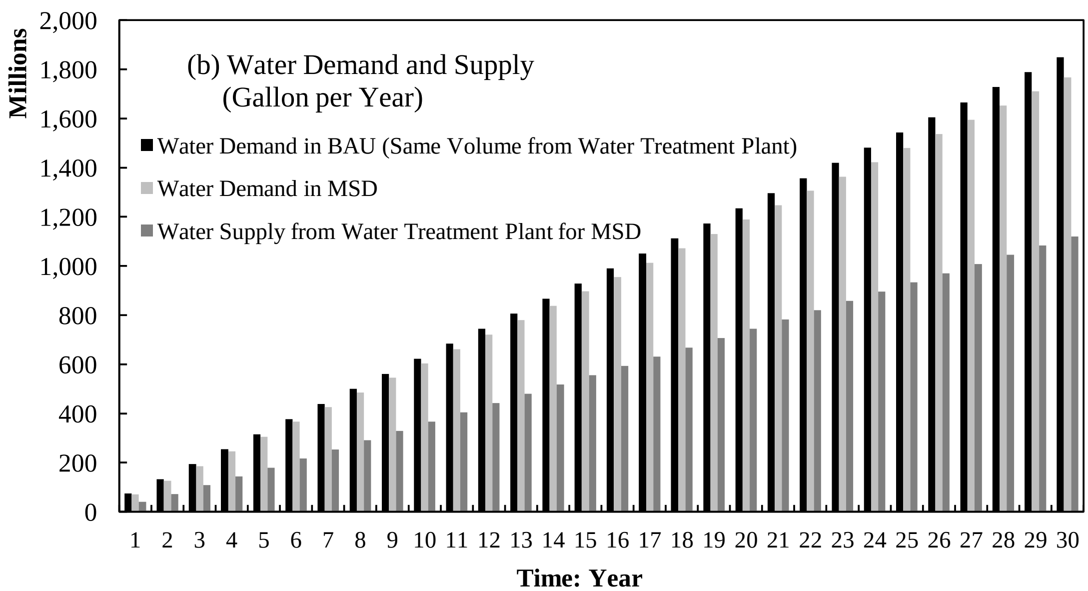


Figure 3.3. Economic-environmental benefits in MSD and BAU: (a) the accumulated tax revenues minus the accumulated cost for storm water management given the predefined tax rate for storm water management; (b) the annual water demand and water supply from the water treatment plant for the developed area based on the water demand in metro Atlanta.

Overall, this study has developed an agent-based housing market model that incorporates our understanding of the interactions among fees to incentivize LID adoption, willingness to pay for properties and tax revenues for infrastructure improvement (e.g., rainwater harvesting, storm runoff control, traffic mobility). The ABM may be extended to the city level to examine the influence of the connections among infrastructure systems (e.g., transportation, water and energy), economic flows, house and work location, and land use. The extended model may also be able to evaluate technical, economic, and political strategies for making urban systems more sustainable.

The real housing market is much more complex than that simulated with the ABM, because homebuyers' and developer's decision making involves more issues than I have considered. Issues, which were not considered, but also influence homebuyers' and developer's decisions include: (1) school district quality, (2) crime rate, (3) social norms and status, (4) childcare availability, (5) land acquisition, (6) permit issuance, (7) project financing, (8) market competition between many developments on a city wide basis, (9) influence of other markets, for example, the financial or labor markets, and (10) diversity of housing types and transportation choices. In addition, it would also be useful to include how homebuyers share their opinions with one another and how this influences their decisions.

The ABM that I have developed is therefore only a first step towards developing a useful model that policy makers can use. However, the ABM can be greatly improved in the future, taking advantage of tremendous increases in computation power,[20] greater availability of socioeconomic data [68] and an increased understanding of human behavior [69, 70] including the actors that are involved in (re)development (i.e. interactions between developers, homebuyers, government, etc.). I believe that such an improved and expanded ABM will allow us to predict the adoption of more sustainable approaches for urban (re)development in response to policy instruments.

CHAPTER 4

LATENT CLASS ANALYSIS ON HETEROGENEOUS PREFERENCE AND CHOICE: MARKET POTENTIAL FOR SMART GROWTH NEIGHBORHOODS IN THE UNITED STATES

4.1 Introduction

Calibration of ABMs is an important step in developing a robust and reliable computational model for investigating complex and adaptive urban systems. In terms of the ABM in chapter 2, one of its essential components is individual's preference and choice of residential community. The way this preference is determined in chapter 2 is based on the elasticity of the willingness to pay for community design attributes identified as important in the literature. In this chapter, I explore an alternative analytic method based on the use of survey data to develop a model of an individual's choice of the type of community to live in.

Discrete choice models (DCMs) have been widely used to analyze how individuals make choice decisions from a set of alternatives. The most popular theoretical framework for DCMs is derived from random utility theory (RUT), in which decision makers are assumed to pursue utility maximization.[71, 72] To date, a variety of DCMs has been substantially developed, including the multinomial logit (MNL) model, nested logit (NL), generalized extreme value (GEV) model, and mixture logit model.[73] In this study, I selected the latent class (LC) model, belonging to the class of mixture logit models, to account for the heterogeneity in people's choices.[74-76] Preferences for housing, neighborhood and accessibility vary from homebuyer to homebuyer. Accounting for this preference heterogeneity can contribute to improving the modeling performance and understanding the diverse demands placed on smart growth.[77] In the LC model, parameters, weights and choices are distinctive across the unobserved subgroups, or latent classes. Belonging to a specific class membership is probabilistic, depending on an individual's socioeconomic characteristics and attitudes towards the choices offered. For instance, Rid and Profeta [78] identified three segments in the private homebuyers' market with distinctive "environmental awareness" and preferences for sustainable housing in Germany.

In this study, I applied the LC choice analysis to data from a 2011 National Association of Realtors (NAR) community preference survey of 2,071American adults, to understand U.S. citizens' preferences and choice behavior towards smart growth neighborhoods versus conventional sprawling communities.[79] On the basis of this LC choice model, I derive the difference in the weights of design properties on the choice model's utility function across different classes. I identify the impacts of socioeconomic status and attitudes on an individual's class membership. I then apply this choice model to evaluate the market potential of a hypothetical smart growth neighborhood (i.e., the probability of an individual choosing the smart growth neighborhood versus a conventional sprawling community). I further evaluate the impact of the model's implied market segmentation and potential for smart growth neighborhoods through an agent-based market diffusion model. Similar to the ABM in Chapter 2, this market diffusion includes the individual-level adoption and demand-supply rules to predict the macro-level diffusion of smart growth neighborhoods. The results of these individual choice and market diffusion models should be helpful to urban planners, policymakers and developers in further exploration of strategies for investing and promoting smart growth.

4.2 Literature Review

The literature review covered three topics: 1) residential location choice modeling; 2) preference for smart growth neighborhoods and the factors that affect these preferences; and 3) the use of the residential location decision-making process in a bottom-up approach to urban growth modeling.

4.2.1 Residential Location Choice Modeling

There are several utility-based choice models, such as MNL, NL, GEV and mixture logit model.[73, 80] The MNL assumes that individuals are homogenous and the relative odds of any two selection outcomes are irrelevant to the change in the rest of the alternatives. The violation of these assumptions can lead to biased estimation.[81] In reality, an individual's preferences vary with his or her socioeconomic status. The modification of one alternative can change the probability of the substitutes (i.e., substitute goods which can replace each other in use) as well as the relative odds of the substitutes being selected.

The MNL has been improved by allowing model parameters to vary randomly over individuals. However, it still does not well explain why individuals are different from each other.[74] The nested logit, or NL is another alternative of the MNL, which groups with similar alternatives into a nest and allows the alternatives within the same net to share a similar choice sensitivity.[80] The NL is useful for modeling individuals making decisions in a sequential fashion. For example, households may first decide whether to move or stay then decide where to move.[82] However, the estimation of the NL is sensitive to the formation of nests.[80] Within the same nest, the relative odds of any two selection outcomes remain invariant across individuals making the choice and despite a change in the rest of the alternatives. The GEV model allows for a more flexible substitution pattern among the alternatives.[83] But the GEV can still inadequately represent the variation in individual preferences.[81]

The mixture or mixed logit model is a highly flexible DCM, which accounts for both substitution effects among alternatives and heterogeneous preference levels among individuals.[74, 81] The LC choice model used in this present research is a specific form of mixture logit models. In modeling residential location choice, the latent classes represent different segments in the population, each of which shows its own preferences and choice behavior. Olaru et al. [84] identified two classes with significant heterogeneity in the population of Perth, Western Australia in terms of their evaluations of transit-oriented development. Liao et al. [85] identified two classes that show distinct preferences for compact development in the Wasatch Front, Utah. Both studies employed socioeconomic characteristics and personal attitudes to interpret the preference heterogeneity.

The estimation of the LC choice model requires data from a discrete choice experiment (DCE).[77] The DCE asks consumers to state their preferences for a set of hypothetical scenarios comprised of a set of attributes and different levels on these attributes.[86] The advantage of using the DCE is its ability to approximate an individual's trade-offs or balancing between alternatives. Also the DCE allows the elicitation of preferences for attributes associated with similar products and guarantees these attributes are orthogonal for the LC choice model.

Considering the flexibility of the LC choice model and the availability of DCE results in the NAR survey, I adopted the LC choice model to evaluate U.S. citizens' preference for smart growth neighborhoods.

4.2.2 Preference for Smart Growth Neighborhoods

Residential location choice modeling is a way of approximating the tradeoffs among a set of communities comprising different design attributes. Influential attributes that affect people's choice of where to live include the type of houses (e.g. single-family house, apartment), locations (e.g. commute time to work), and amenities (e.g. quality of schools, access to food, and public transportation).[87, 88]

Preference for smart growth neighborhoods also varies among households depending on socioeconomic characteristics (e.g. lifestyle, life stage, housing tenure, and education). Lifestyle refers to a certain desirable way of living and drives the decision of where to live. Walker and Li [89] identified three lifestyle segments in Portland, Oregon in 1994, including suburban dwellers (43% of total households), urban dwellers (30% of total households) and transit-riders (27% of total households). Suburban dwellers prefer larger residences while transit-riders prefer lower travel time to work by transit. Life stage refers to the division of life into different stages, such as young and single, married, married with young children, married with grown up children and retired. In different stages, people exhibit different demands and preferences for living spaces and neighborhood environments.[90] Households with children appreciate the value of green space and recreational opportunities, while those without children prefer locations with easy access to services.[91] Home ownership and education are the other two common indicators for preference heterogeneity. Renters tend to consider residences close to workplaces while owners focus more on the quality of the residence.[85] Many well-educated households in recent years have chosen to live in multi-functional, high-density environments and larger cities.[92]

Psychological factors are also included in the residential location choice model to explain the source of preference heterogeneity. These psychological factors accounts for individual perceptions and attitudes towards quality of life, neighborhood, and environment.[72] For example, households with high environmental awareness are more likely to choose more sustainable and compact houses.[78] One typical method of measuring individual attitudes is asking whether something (e.g. a mix of people from various income levels) is important when deciding where to live. People also often have distinct opinions about various aspects of community design, which can also help planners to understand an individual's housing location choice behavior. In this study, I refined and updated the U.S. citizens' preferences for smart growth neighborhoods using the 2011 NAR community preference survey data. I explicitly interpreted the estimated preference and the corresponding behavior of choosing smart growth neighborhoods from the LC choice model.

4.2.3 Bottom-up Urban Growth Modeling

Urban growth modeling is an important tool for understanding and managing the development of cities. One of these modeling techniques is called bottom-up simulation, which predicts urban growth as an emergent property from thousands of decisions and interactions.[30, 93] These decisions include but are not limited to residential (re)location choice, travel activities, and new development.[94] These decision models are the foundation of the bottom-up modeling and they should properly reflect the change of behavior in response to the environment change. In this study, I estimate a residential location choice model to predict individual adoption of smart growth neighborhoods, comprised of a certain set of design features. I also build a market diffusion model which includes individual adoption of smart growth neighborhoods and demand-supply rules. I then show how the market growth for smart growth neighborhoods and how the designs of smart growth neighborhoods can influence the emergent market diffusion.

4.3 Materials and Methods

4.3.1 Latent-class Choice Model

In this study, a LC choice model is developed to predict the probability of an individual choosing a smart growth neighborhood over a conventional sprawling community. In the LC choice model, the probability of individual *i* choosing alternative *m* equals the joint probability of the individual *i* belonging to class *x* and choosing alternative *m*. In the NAR survey, the DCE section presented seven choice sets to the respondents, with each set consisting of one sprawling community and a smart growth neighborhood (Table 4.1). The design attributes involved in describing the community contain lot size and design, accessibility, commute time to work and the availability of public transportation (Table 4.2). Respondents were asked to choose the preferred one out of the two alternatives in each set. Using the LC choice model to analyze these responses in the DCE made it possible to capture the heterogeneous importance of design attributes in determining the behavioral responses across different latent classes, as well as the effect of individual socioeconomic and psychological characteristics on class membership.

Table 4.1. The seven choice sets in the DCE and the eighth choice set for evaluation in this study: each set has two alternatives, one is termed "conventional sprawling community" and the other one is "smart growth neighborhood"; each set has different features that can distinguish the two community types.

Set ID	Conventional sprawling community	Smart growth neighborhood
1	Houses are built far apart on **larger lots** and you **have to drive** to get to (schools, stores and restaurants/parks, playgrounds, and recreation areas).	Houses are built close together on **smaller lots** and it is **easy to walk** to (schools, stores and restaurants/parks, playgrounds, and recreation areas).
2	Houses are built far apart on **larger lots** and you **have to drive** to get to schools, stores and restaurants.	Houses are built close together on **smaller lots** and it is **easy to walk** to schools, stores and restaurants.
3	Houses are built far apart on **larger lots** and you **have to drive** to get to parks, playgrounds, and recreation areas.	Houses are built close together on **smaller lots** and it is **easy to walk** to parks, playgrounds, and recreation areas.
4	Houses are **larger** on **larger lots**, and you would have a longer commute to work, **40 minutes or more**.	Houses are **smaller** on **smaller lots**, and you would have a shorter commute to work, **20 minutes or less**.
5	The neighborhood has **houses only** and you **have to drive** to stores and other businesses.	The neighborhood has **a mix of houses and stores** and other businesses that are **easy to walk to**.
6	Own or rent **a detached, single-family house**, and **have to drive** to shops and restaurants and have a **longer commute to work**.	Own or rent **an apartment or townhouse**, and have **an easy walk** to shops and restaurants and have a **shorter commute to work**.
7	There are **only single family houses** on **large lots**. There are **no sidewalks**. Places such as shopping, restaurants, a library, and a school are within **a few miles** of your home and you **have to drive** to most. There is enough parking when you drive to local stores, restaurants and other places. Public transportation, such as bus, subway, light rail, or commuter rail, is **distant or unavailable**.	There is a **mix** of single family detached houses, townhouses, apartments and condominiums on various sized lots. Almost all of the streets have **sidewalks**. Places such as shopping, restaurants, a library, and a school are within **a few blocks** of your home and you can **either walk or drive**. Parking is **limited** when you decide to drive to local stores, restaurants and other places. Public transportation, such as bus, subway, light rail, or commuter rail, is **nearby**.
8	There are **only single family houses** on **large lots**. There are **no sidewalks.** Places such as shopping, restaurants, a library, and a school are within **a few miles** of your home and you **have to drive** to most. Places such parks, playground, and recreational area are within **a few miles** of your home and you **have to drive** to most. There is enough parking when you drive to local stores, restaurants and other places. Public transportation, such as bus, subway, light rail, or commuter rail, is **distant or unavailable.** Commute time to work is **more than 40 minutes.**	There is a **mix** of single family detached houses, townhouses, apartments and condominiums on various sized lots. Almost all of the streets have **sidewalks.** Places such as shopping, restaurants, a library, and a school are within **a few blocks** of your home and you can **either walk or drive. Places** such parks, playground, and recreational area are within **a few blocks** of your home and you can **either walk or drive.** Parking is **limited** when you decide to drive to local stores, restaurants and other places. Public transportation, such as bus, subway, light rail, or commuter rail, is **nearby.** Commute time to work is **less than 20 minutes.**

In order to evaluate the impact of attitudes on choice behavior, I applied a principal components analysis (PCA, SPSS, version 21.0) to extract a reduced number of interpretable principle components, or attribute metrics, from the original questions, "in deciding where to live, indicate how important each of the following would be to you: very important, somewhat important, not very important, or not at all important". This resulted in the extraction of four principal components. The first component relates to the diversity of the neighborhood environment, such as a mix of people, multiple housing types, and green designs. The second component signifies the importance of big and sprawling lot design. The third component captures the importance of accessibility in deciding where to live. The fourth component concerns the privacy of the house. Together these four components explained around 75% of the total variation in responses to the original 16 questions in the survey. The scores on the four components for each respondent are included as variables (i.e., diverse neighborhood environment, big and sprawling lot design, accessibility, and privacy) in the LC choice modeling.

I used the Latent GOLD Choice 4.5 software for class-specific choice estimation.[95] The segmentation of classes was estimated according to the respondent's socioeconomic and psychological variables (Table 4.2). The corresponding choice behavior of each class was estimated according to the probability formulation derived from RUT.[96] Accordingly, the conditional probability of the individual *i* choosing alternative *m* depending on class membership *x* has the form of a logistic probability (Eq. 4.1). The utility that individual *i* receives from alternative *m* depending on class membership *x* is determined by design attributes and the weights (Eq. 4.2). The estimation of the LC choice model is by means of Maximum Likelihood (ML) and the determination of optimal class number is based on Bayesian Information Criterion (BIC) and classification errors.[72, 85] A smaller BIC indicates a better model fit with a smaller number of parameters to be estimated.

$$P(y_{it} = m \mid x) = \frac{\exp(\eta^{t}_{m|x})}{\sum_{m'=1}^{M} \exp(\eta^{t}_{m'|x})} \tag{4.1}$$

where $\eta^{t}_{m|x}$ donates individual *i*'s utility associated with the alternative of *m* in choice set *t*, and

$$\eta^{t}_{m|x,z_t} = \beta^{con}_{mx} + \sum_{p=1}^{P} \beta^{att}_{xp} z^{att}_{tmp} \tag{4.2}$$

where $\eta^{t}_{m|x,z_t}$ donates the utility of alternative *m* in choice set *t* given individual *i* belonging to class *x*; β^{con}_{mx} is the alternative-specific constant with the restriction $\sum_{m=1}^{M} \beta^{con}_{mx} = 0$; β^{att}_{xp} is the effect of attributes (z^{att}_{tmp}). All the regression coefficients are class-specific.

Table 4.2. The attributes and levels of community design and socioeconomic features used in the DCE and LC choice model.

	Item	Level of the attributes	Value assigned
Design Attribute	Lot design	House	0
		Large lot	1
		Large lot, large house	2
		Single-family house	3
		Large lot, single-family house	4
	Accessibility	Housing only	0
		Close to recreational sites	1
		Close to school, stores, etc	2
		Close to recreational sites and school, stores, etc	3
		Mixed land use	4
	Commute to work	More than 40 minutes	0
		Less than 20 minutes	1
	Public transportation	Drive only	0
		Public transit is nearby	1
Socioeconomic Attributes	Gender	Male	0
		Female	1
	Age	18-29	1
		30-39	2
		40-49	3

	50-59	4
	60+	5
Region	Northeast	1
	Midwest	2
	South Atlantic	3
	Inland South	4
	West	5
Education	<HS/HS	1
	Some college	2
	College graduate	3
	Post graduate	4
Income	<$25K	1
	$25-50K	2
	$50-75K	3
	$75-100K	4
	$100K+	5
Home ownership	Own	0
	Rent	1
Current residency	City	1
	Suburban - mixed	2
	Suburban - housing only	3
	Small town/rural	4
Marital status	Married	1
	Single	2
	Divorced/separated/widowed	3
Kids under 18	No	0
	Yes	1
Employed	No	0
	Yes	1
Commute	By car	0
	Other mode	1

4.3.2 Market Diffusion Model

I developed a dynamic diffusion model that predicts the rate of smart growth neighborhood adoption in the housing market. The purpose of this diffusion model is to understand the impact of the potential market demand for smart growth neighborhood living on the long-term land use pattern. The diffusion model presents the interactive demand and supply process in the real estate market, following the idea of an agent-based housing market model in chapter 2. In year *t*, the probability ($P_{t,s}$) of an individual home buyer purchasing a house in a smart growth neighborhood is determined by Eq. 4.3:

$$
\begin{aligned}
P_{t,s} &= \frac{f_s \exp(U_s)}{f_s \exp(U_s) + f_c \exp(U_c)} \\
&= \frac{f_s}{f_s + f_c \times \dfrac{\exp(U_c)}{\exp(U_s)}} \\
&= \frac{f_s}{f_s + f_c \times (\dfrac{\exp(U_c)+\exp(U_s)}{\exp(U_s)} - 1)} \\
&= \frac{f_s}{f_s + f_c \times (\sum_{i=1}^{4} P_i \dfrac{1}{P_{s|i}} - 1)}
\end{aligned}
\tag{4.3}
$$

where, f_s , f_c is the market share of houses in smart growth neighborhoods and conventional sprawling communities, respectively; U_s, U_c is the utility of living in houses locating in smart growth neighborhoods and conventional sprawling communities; P_i is the probability of the individual belonging to the class *i* (with a total of four classes from the LC choice model); and $P_{s|i}$ is the probability of choosing the smart growth neighborhood given class *i*.

Accordingly, the sale of houses in smart growth neighborhoods in year *t* ($Sale_{t,s}$) is calculated as follows (Eq. 4.4):

$$
Sale_{t,s} = \min(NB_t \times P_{t,s}, S_{t,s}) \tag{4.4}
$$

where, NB_t is the number of home buyers in year *t*; $S_{t,s}$ is the supply of houses belonging to smart growth neighborhoods in year *t*.

Further, the projected demand for houses in smart growth neighborhoods in year *t*+1 ($D_{t+1,s}$) is assumed to equal the $NB_t \times P_{t,s}$. The supply of houses in smart growth neighborhoods in year *t*+1 ($S_{t+1,s}$) is determined by Eq. 4.5,

$$
S_{t+1,s} = \max(D_{t+1,s}, S_{t,s} - Sale_{t,s}) \tag{4.5}
$$

The starting conditions of the diffusion model include: (1) NB_t constantly equals 1,000 assuming the stable increase of home buyers; (2) the total supply of residential properties equals 1,000 in year 0, for which 80% are built in conventional sprawling communities and 20% in smart growth neighborhoods. The fraction of sold residential properties (f_s^T) in smart growth neighborhoods after year *T* is emergent as follows (Eq. 4.6):

$$f_s^T = \frac{\sum_{t=1}^{T} Sale_{t,s}}{\sum_{t=1}^{T} Sale_{t,s} + \sum_{t=1}^{T} Sale_{t,c}} \tag{4.6}$$

The f_s^T value shows the time-dependent diffusion curves (i.e., adoption rate) of residential properties in smart growth neighborhoods. In other words, the f_s^T value and corresponding diffusion curve indicate the progress of land development following smart growth principles. I use the results for f_s^T to assess whether the market potential for smart growth neighborhoods can contribute significantly to less sprawling land development.

4.4 Results

4.4.1 LC Choice Model

I selected a four-class choice model as the optimal estimation because it had the smallest BIC and only 10% classification errors. The estimated class membership parameters and utility function parameters are shown in Table 4.3. All the coefficients in the utility function are significant at the 5 percent level. Also the differences of coefficients are significant across the four classes at the 5 percent level.

Table 4.3. Four-class choice model estimates for community attributes, socioeconomic and attitudinal variables.

Model for Choices					
	"Likely sprawling"	"Conditionally sprawling"	"Conditionally compact"	"Likely compact"	Overall
R2(0)	0.70	0.33	0.17	0.98	0.59
Community Attributes [a]					
Lot design	3.25	2.62	-0.63	-6.51	
Accessibility	-0.41	0.21	0.25	0.87	
Commute time to work	5.71	6.48	-1.72	1.00	
Public transportation	11.41	10.97	-2.17	1.00	
Model for Classes					
Respondent's socioeconomic and attitudinal variables					p-value
Intercept	0.50	-0.47	0.11	-0.13	0.63
Gender	0.02	0.06	0.03	-0.11	0.78
Age	-0.03	0.04	0.02	-0.04	0.66
Region	0.12	-0.03	-0.03	-0.06	0.10
Education	-0.16	-0.07	0.06	0.17	0.01
Income	-0.06	0.04	0.07	-0.04	0.25
Home ownership	-0.64	0.25	0.05	0.33	0.00
Current residency	0.33	-0.03	-0.15	-0.15	0.00
Marital status	-0.66	0.40	0.15	0.11	0.00
Kids under 18	0.14	0.12	-0.12	-0.13	0.34
Employed	0.99	0.08	0.13	-1.20	0.00
Commute mode	-0.84	0.27	-0.11	0.68	0.01
Head of Household	0.58	-0.35	0.01	-0.24	0.01
Diverse neighborhood environment	-1.01	0.17	0.21	0.64	0.00
Big and sprawling lot design	0.38	0.21	-0.02	-0.58	0.00
Accessibility	-1.15	0.22	0.23	0.70	0.00
Privacy	1.55	0.03	-0.38	-1.20	0.00

a. All the coefficients are significant at the 5 percent level; also the coefficients are significantly different across the four classes.

I named the four classes as "likely sprawling", "conditionally sprawling", "conditionally compact", and "likely compact" according to the positive and negative impacts of design attributes on the utility value. In detail, for the "likely sprawling" class, the coefficient of lot size and design is positive which means the utility increases as the lot size and design tends to be sprawling. In contrast, the negative effect of accessibility indicates the decline of the utility as the community gets close to recreational and commercial areas. Consequently, the “likely sprawling” class mostly chooses a conventional sprawling community. However, if the commute to work becomes less than 20 minutes and public transit is available, there is a slight increase in the probability of choosing a smart growth neighborhood for the “likely sprawling” class. For the “conditionally sprawling” class, both the lot size and design, and accessibility variables are positive. But the weight of accessibility is much smaller than the lot size and design given the same scaling of the value. Generally, this class has a relatively higher probability of choosing to live in a conventional sprawling community. A commute to work of less than 20 minutes and the availability of public transit can increase the adoption of a smart growth neighborhood made by the “conditionally sprawling” class. For the “conditionally compact” and “likely compact” classes, the coefficients of lot size and design are negative, which shows the decrease in utility as the community becomes sprawling. The coefficients of accessibility are positive, indicating the increase in utility as the community has easy access to the areas for recreational and commercial activities. Accordingly, these two classes tend to choose smart growth communities. In contrast, the “conditionally compact” class is more likely to live far away from workplaces and public transit service.

Of the total respondents, 32% belongs to the “likely sprawling”, 26% belongs to the “conditionally sprawling”, 23% belongs to the “conditionally compact”, and 19% belongs to the “likely compact” class. Table 5 shows the results of the effects of individual’s socioeconomic and psychological characteristics on class membership. Among these variables, the level of education shows a significant impact at the 5 percent level. Those who have a higher level of education have a higher probability of belonging to the “likely compact” class, while people with a lower level of education tend to belong to the “likely sprawling” class. Employment is another significant factor that influences the class membership. People who are employed less likely to be in the “likely compact” class than are unemployed people. Other significant socioeconomic factors include home ownership, head of household, commute mode, marital status, and current residency (Table 4.2). The impact of these variables on class membership can be understood according to the positive and negative contribution to the likelihood of the four classes.

The four attitudinal variables from PCA are included in the class segmentation model in order to understand the impact of personal attitudes on choice behavior. The p-value indicates the effects of all the four attitudinal variables are explicit and statistically significant (see Table 4.3). Holding other variables constant, if a diverse neighborhood environment is not seen by an individual as important, then I expect that there is more than 50% probability he or she belongs to the “likely sprawling” class. If a person feels the big and sprawling lot design variable to be very important in deciding where to live, there is less than a 10% probability that he or she is a member of the “likely compact” class. The effects of the other two attitudes associated with accessibility and privacy are illustrated in Figure 4.1.

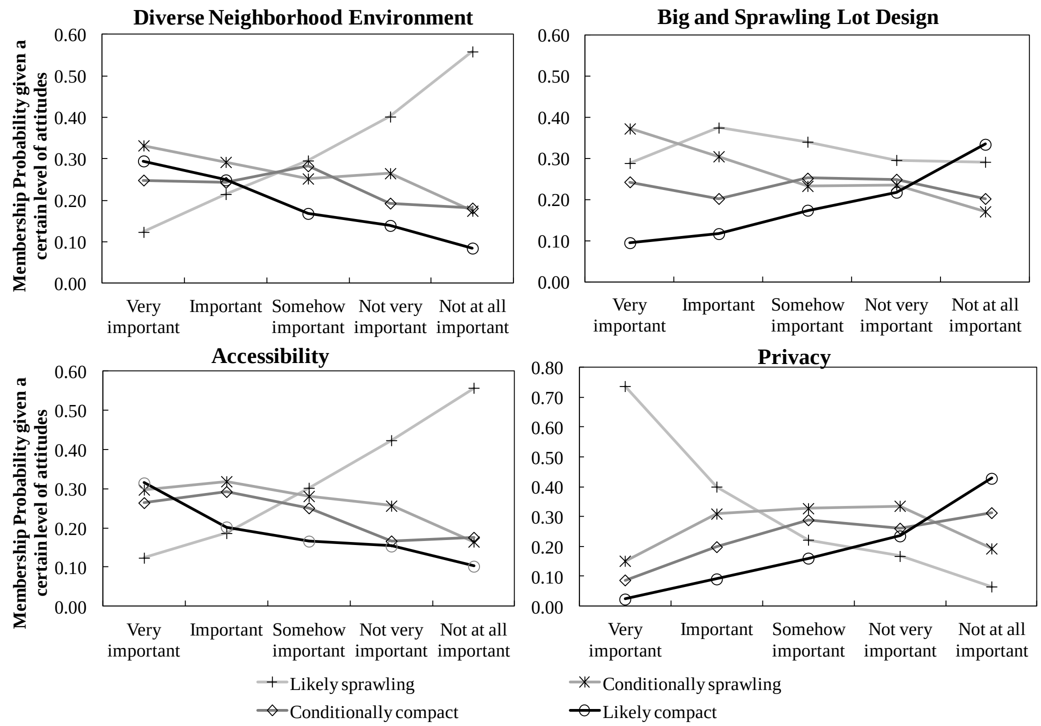


Figure 4.1. The impact of individual's four attitudinal variables on class membership.

The estimated LC choice model can be applied to evaluate the proposed smart growth neighborhood. For illustration, I created the 8th choice set, in which the smart growth neighborhood contains a more comprehensive set of smart growth features than those presented in the NAR survey (Table 4.1). The result shows that there is an 83% probability of an individual home buyer being located in the proposed smart growth neighborhood (Figure 4.2). Of these smart growth neighborhood selectors, around 90% are in the "likely compact", "conditionally sprawling" and "likely sprawling" classes. In the 7th choice set presented in the NAR survey, only 56% of total choose the smart growth neighborhood. The primary contribution to the probability increase comes from the shorter commute to work and the enhanced local accessibility. There are still 17% of home buyers choosing sprawling community and almost 100% of them belong to the "conditionally compact" class. The reason for not choosing the smart growth neighborhood is due to the negative impact of being close to workplaces and public transit. Thus, I expect that the potential market demand for smart growth neighborhoods is influenced by the design details put forward by local urban planners and real estate developers. By adding more amenities into smart growth design, my results suggest that we may be able to achieve a higher-level market potential for smart growth. However, it is worth noting that not all the smart growth neighborhoods can be built as described in this 8th choice set. Some percentage of the smart growth neighborhoods described in the 1-7th choice set are not close to workplaces or amenities. As a result, we might observe a lower average market potential for smart growth neighborhoods in such areas, which is less than 83% result reported above.

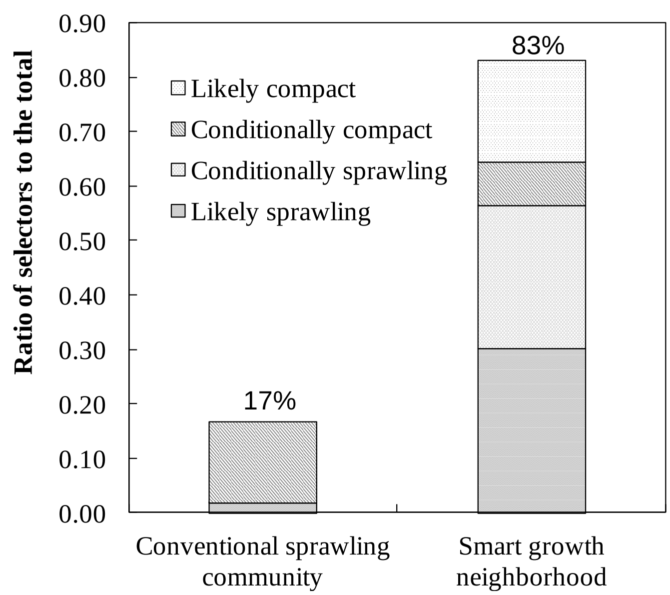


Figure 4.2. The estimated probability of an individual choosing smart growth neighborhood over conventional sprawling community giving the 8th choice set (Table 4.1).

4.4.2 Diffusion of Smart Growth Neighborhoods

Building on the above-described diffusion modeling, I evaluated the impact of the potential demand for smart growth neighborhood living on the long-term land use pattern. I selected the 7th and 8th choice set (Table 4.1) for the comparison. In the 7th choice set, there is 56% probability of an individual home buyer choosing the smart growth neighborhood. In order words, assuming the same probability of considering houses in a smart growth neighborhood and a conventional sprawling community, 56% of home buyers choose the smart growth neighborhood. Thus, the percent of purchased houses that belong to smart growth neighborhoods reaches 56% at market equilibrium. However, I fail to observe the same market share according to the diffusion curve. In contrast, I see the decline of market share for smart growth neighborhoods (Figure 4.3). This result appears to be caused, at least in part, by the market inefficiency in providing sufficient smart growth neighborhoods (only 20% of properties belonging to smart growth neighborhoods) and hence limiting the consideration of houses in such neighborhoods. This market inefficiency might be overcome to some degree once there is a stronger demand for smart growth neighborhood living. I observe an increasing adoption rate of smart growth neighborhood living from the 8th choice set, where there is an 83% probability of an individual choosing a smart growth neighborhood when he/she compares the two community types (Figure 4.3). The housing supply limitation is overcome in this case due to the high demand for the proposed smart growth neighborhood. This leads to the conclusion that, as we might expect, market potential is an important variable in driving a movement towards smart growth development, and that this market potential is in turn influenced by the way smart growth neighborhoods are planned and built.

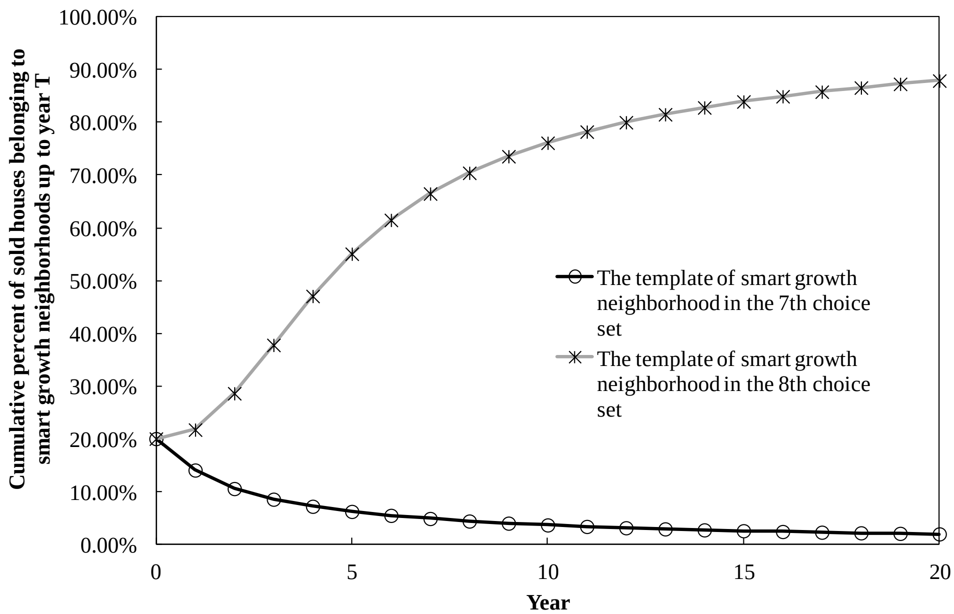


Figure 4.3. Market diffusion patterns of the two designs of smart growth neighborhoods in the 7th and 8th choice set (Table 4.1).

4.5 Discussion

In this study I have applied latent class choice analysis to data from a NAR 2011 community preference survey. I identified four classes of respondents, termed "likely sprawling", "conditionally sprawling", "conditionally compact" and "likely compact", where class membership is based on an individual's socioeconomic and attitudinal characteristics. The corresponding behavior of choosing a smart growth neighborhood to live in was also estimated according to a set of class-specific utility functions. Compared to previous studies, our analysis demonstrates a more comprehensive classification of U.S. citizens that have distinctive preferences for smart growth. At the regional level (i.e., Northeast, Midwest, South-Atlantic, Inland South and West), the distribution pattern of the four classes does not show a significant difference (p=0.10). However, the distribution of the four classes may vary across individual metropolitan areas due to differences in local-specific economic (e.g., unemployment rate, housing and transportation cost) and social (e.g., environmental awareness) conditions. On average, Atlanta residents are less interested in transit-oriented and walkable neighborhoods than for example, Boston, which implies a higher percentage of "likely sprawling" class and a lower percentage of "likely compact" class in Atlanta than Boston.

The primary limitation of using the NAR data is the lack of understanding of the market effect on the adoption of smart growth neighborhoods. Even asking for the willingness to pay for a particular property does not objectively reflect the deal price. The optimal solution is to combine the data of market sales and surveys to assess the price effect and preferences for smart growth neighborhoods.[97] Here, I assume that the impacts of market price and community attributes on the adoption are independent. As a result, the price effect is included as the unobserved utility in the error term. Overall, I believe the analysis, built upon the 2011 NAR community preference survey, offers some useful quantitative insights for urban planners, policy makers and real estate developers looking to promote smart growth.

Another limitation in this study is the lack of the understanding of the impact of K-12 school quality on community choice.[87] The DCE does not include school quality as an important variable, despite the fact that 45% of the respondents stated the quality of K-12 schools is very important in deciding where to live. In reality, the issue of the uneven school quality distribution between urban and suburban areas has been raised since land development became sprawling.[98] Although the urban area has a higher incentive for smart growth than suburban areas, the poor schools in urban areas might hinder the economic prosperity resulting from smart growth. Therefore, policies that help improve the quality of school systems in urban areas may prove essential to the success of smart growth.

The development of the LC choice model allows the estimation of individual-level adoption of smart growth neighborhood living as compared to locating residence in a conventional sprawling community. In this study, I find that the high market potential can be achieved by adding more amenities (e.g., shorter commute time to work, easy access to recreational places). Meanwhile, I point out that not 100% smart growth neighborhoods can be built as described in our most appealing (the 8^{th}) choice set. One reason is the shortage of land supply, in particular, in the area close to commercial business districts. The shortage of smart growth neighborhoods as described in our 8^{th} choice set can lead to a higher sale price, which may induce the substitution with the conventional sprawling community. The overall market potential should be less, therefore, than our prediction based on the 8^{th} choice set.

Further, a diffusion model demonstrates a simple demand and supply dynamic in the housing market that is used to illustrate the diffusion of smart growth neighborhood adoption. The modeling shows how market inefficiency in supplying smart growth neighborhood options can lower the residential market share of smart growth neighborhoods. An increased demand for smart growth neighborhoods should be able to overcome some of this market inefficiency through local suitable planning and design initiatives. That is, a higher market demand, and market share for smart growth, less sprawling neighborhood development seems feasible.

Land development is a complex and adaptive process, which is far more sophisticated than the mechanism of the diffusion model.[99] In the diffusion model, I only compare two neighborhood types which cannot represent 100% of neighborhood types in reality. I also simplify the complex process involving the planning, location, design and financing of smart growth. Therefore, the diffusion model is not intended to predict the market share of smart growth neighborhoods precisely. In fact, the emerging systematic approach that accounts for the complexity of land development is indeed necessary to plan smart growth that can ultimately meet people's preferences and needs.[100] Part of the reason for the failure of smart growth initiatives has been the lack of systematic planning approaches for smart growth. Systematic planning should allow urban planners to figure out the optimal solution to integrating smart growth into the current land and infrastructure configuration at different levels of geographic coverage from the micro neighborhood up to the macro city, allowing the location and design of smart growth neighborhoods to be better optimized and customized.

4.6 Conclusion

This study contributes to the limited understanding on heterogeneous preference and behavior of Americans choosing to live in smart growth neighborhoods. The results indicate that there is considerable heterogeneity in preference and the corresponding choice of where to live by Americans. The impacts of both socioeconomic and attitudinal characteristics are found to be significant in neighborhood choice. The analysis of heterogeneous preference and choice behavior makes it possible to demonstrate the potential market demand for smart growth neighborhoods. According to the diffusion model, the market potential for the smart growth neighborhood turns out to have a significant impact on land development. Thus, both heterogeneous choice behaviors and market potential should be considered when designing the form and location of smart growth neighborhoods. Lastly, a more systematic approach to planning for smart growth is needed in order to effectively realize this market potential.

CHAPTER 5

PREFERENCE AND ADOPTION OF LOW-IMPACT, TRANSIT-ORIENTED DEVELOPMENT: IMPLICATIONS FOR MORE COMPACT AND SUSTAINABLE DEVELOPMENT IN METROPOLITAN ATLANTA

5.1 Introduction

During the past few decades, low-density residential development (e.g., single-family and semi-detached houses in suburban areas) has dominated the land use pattern of metropolitan Atlanta. In 2014, Atlanta is the most sprawling big metro region (i.e., regions over 1 million in population) in the United States.[101] Although low-density development provides comfortable living spaces, the negative impacts of low-density development are becoming more obvious and serious in the metro area. Low-density development caused longer driving distances for work, food, shopping and entertainment. At the same time, more investments and resources are needed to address the challenge of aging infrastructures (e.g., water/wastewater networks, gas pipelines, and highways). Unfortunately, property tax revenues are insufficient to maintain the quality of infrastructures in low-density development.[102] To solve the problems resulting from sprawl, alternative urban growth patterns are indeed required.

Urban systems are complex and adaptive. Complexity results from the millions of decisions and interactions of diverse adaptive entities (i.e., citizens, firms, developers, and governments).[103] These decisions and interactions drive the dynamic and evolving interdependence between urban infrastructures and the socioeconomic environment. The interdependence leads to the emergence of specific land use, quality of life, and carbon footprints. To develop more desirable sustainable properties along each of these dimensions requires the understanding and modeling of the complexity. To do so, we should start from a better understanding people's preference and demand for more sustainable infrastructure designs. Further, we should provide a suitable combination of more sustainable features and develop policies that both help and encourage people's adoption of more sustainable infrastructures.

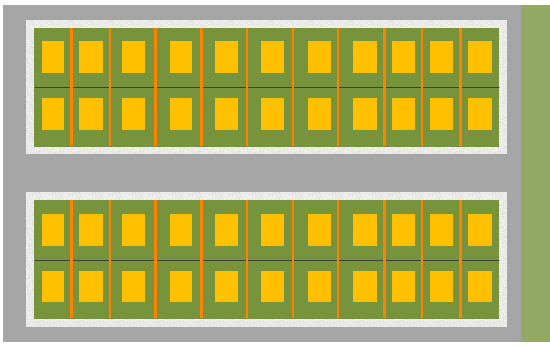
In considering the potential for low-impact development (LID) and transit-oriented development (TOD) to support more sustainable water, transportation and land use within the city, this chapter is devoted to revealing metro Atlanta residents' preferences for LID and TOD. Preference heterogeneity is considered based on an analysis of socioeconomic characteristics and personal attitudes toward LID and TOD. The goal is to evaluate whether the implementation of LID and TOD can contribute to a more compact urban growth.

First, I conducted a survey that asks for people's attitudes on LID and TOD. The survey also includes a discrete choice experiment (DCE) to choose the most/least desirable communities. Details of the survey are presented in the "*Methods and Materials*" section. The survey was published on Mechanical Turk, which is operated by Amazon (https://www.mturk.com/mturk/welcome). Mechanical Turk is a cost-effective platform for collecting survey responses in a short time period. Previous studies that compared Mechanical Turk with laboratory experiments and traditional web studies have shown that the self-selection bias of the sample (i.e., people who are not interested in the topic of the survey may not answer the survey) is smaller using Mechanical Turk than traditional web-based survey.[104] The data quality obtained from Mechanical Turk has also been shown to be comparable to that of laboratory experiment.[105, 106]

With the responses in the DCE, I developed a latent-class residential community choice model. The model identified different classes that show significant heterogeneity in preferences for community designs and simulates the trade-offs among a variety of design attributes (including LID and TOD in particular). These responses are used to approximate the residential community choice decision of these classes. Heterogeneity in preferences for different design attributes across the residents in the metro Atlanta is evaluated according to the degree of the influences on the decision making of different classes. Socioeconomic variables (e.g., household income, education) and personal attitudes on LID and TOD are used to model the class membership. Using the model results, I then developed a visualization of spatial distribution of different classes in the metro Atlanta using Public Use Microdata Sample (PUMS), a set of records about individuals and housing units in the metro Atlanta.

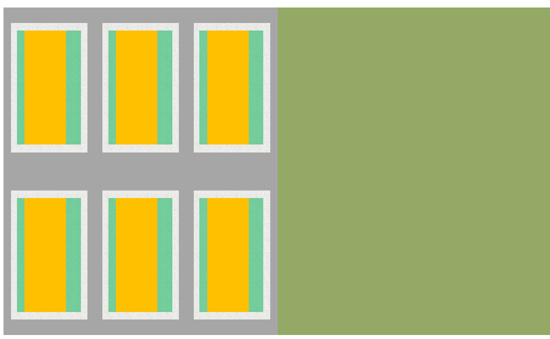
After the development of metro Atlanta resident's community choice model, I evaluated the willingness of citizens to invest in LID and TOD. To do this, I evaluated the impact of the increase in housing price on the adoption of the high-density community (i.e., 4-story apartments) with LID and TOD. Similarly, I also evaluated the impact of increase in housing price on the adoption of the low-density community (i.e., single-family houses) with LID. The design of a single-family housing community and an apartment community is provided in Figure 5.1. Model results show the market potential of LID and TOD in the metro Atlanta.

A final question addressed in this study is whether LID and TOD can serve as incentives to trigger more compact development in the metro Atlanta. To this end, an agent-based market diffusion model was developed that includes homebuyer's community choice and demand-supply rules. This model predicts the adoption of more compact communities under three scenarios. The first scenario is a "Business As Usual (BAU)" scenario, where LID and TOD are unavailable. In the second and third scenarios, TOD is provided, assuming that an investment fund is available from federal and state governments and only high-density communities are permitted in the TOD zone, in an effort to make the TOD profitable. In 2013, the Department of Watershed Management in the City of Atlanta revised the Post-Development Stormwater Management Ordinance to promote the use of green infrastructures (i.e., LID) on new and redevelopment projects in the city. Projects must treat the first 1.0 inch of stormwater runoff with green infrastructures. New single-family homes are required to manage the first 1.0 inch of runoff on their site. The second scenario is defined as a "home-based LID policy" according to the revised ordinance that emphasizes the need for individual home to treat their first 1.0 inch of runoff independently. The third scenario is defined as a "community-based LID policy" that requires new single-family homes to manage the first 1.0 inch of runoff on a community basis. The comparison among the three scenarios demonstrates whether more compact development has a greater potential to emerge by implementing LID and TOD and which policy for LID applied to low-density communities can best contribute to the emergence of more compact development in the metro Atlanta.



Single-family house

10 acre-size residential subdivision	
Lot size	7, 260 sq ft
House size	2,688 sq ft
Housing%	73.5%
Infrastructure%	23.6%
Public space%	2.9%
Dwelling unit	44
Population	110
Population density (person/acre)	11



4-story Apartment home

10 acre-size residential subdivision	
Lot size	1,200 sq ft
House size	1,200 sq ft
Housing%	13.8%
Infrastructure%	22.9%
Public space%	63.3%
Dwelling unit	180
Population	450
Population density (person/acre)	45

Figure 5.1. Residential community design: single-family house representing conventional sprawling development versus apartment home representing more compact development.

5.2 Materials and Methods

5.2.1 Survey Design for Measuring Preference

To measure the preference for low-impact and transit-oriented development, a survey was developed to address the following issues:

1) Demand for housing square footage, number of bedrooms, number of bathrooms and the budget (i.e., either price or rent);
2) Personal attitudes on LID and TOD features;
3) Discrete choice experiment (DCE): the DCE includes fourteen choice sets. In each set, there are four options comprising different levels of designs and price (Table 5.1). Respondents were asked to choose the most and least desirable communities for living in each set. The fourteen choice sets were generated using JMP 10 (SAS Institute Inc., Cary, NC, USA);[107]
4) Respondent's socioeconomic statistics.

The full survey is provided in the Appendix (See Appendix B: Design of the Survey). The survey was approved by Institutional Review Boards (IRB) at the Georgia Institute of Technology. The data was collected from Mechanical Turk, the crowd-source platform developed by Amazon. The study area include the following 30-county in metro Atlanta: Barrow, Bartow, Butts, Carroll, Cherokee, Clayton, Cobb, Coweta, Dawson, DeKalb, Douglas, Fayette, Forsyth, Fulton, Gwinnett, Hall, Haralson, Heard, Henry, Jasper, Lamar, Meriwether, Newton, Paulding, Pickens, Pike, Putman, Rockdale, Spalding and Walton. Respondents were asked to report the county and the zip code of where they are currently living. Respondents reporting an incorrect zip code outside the region were excluded in this study.

Table 5.1. The attributes and levels of design features in the DCE and choice model.

Variables	Definition	Value	
Categorical variable		**Level of attributes**	
House design	House design	Singlefamily: Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area	
		Semidetached: Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area	
		Rowhouse: Row house, 3 stories, 1,800 sq. ft habitable area	
		4story: 4 story stacked flats elevator & corridor access around1 level parking podium, 1,200 sq.ft habitable area	
		8story: 8 story midrise stacked flats over 2 level parking podium, 1,200 sq.ft habitable area	
		16story: 16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq. ft housing square footage	
Green building	Green building design	RWH: Rainwater harvesting for single-family and semi-detached houses	
		GRWR: Green roof and wastewater reclamation for row house and 4-16 story flats	
Numerical variable		**Level of attributes**	*Values assigned to each attribute level to run the choice model (Eq.5.3)*
Public LID	Rain garden, porous pavement and native vegetations for public open space	*No*	0
		Yes for public green space	1
Private LID	Rain garden, porous pavement and native vegetations for private yard	*No*	0
		Yes for private yard	1
Accessibility	Accessibility to food, shopping and entertainment	*Driving in 30 minutes*	0
		Biking in 20 minutes	0.5
		Walking in 10 minutes	1
Green space	Size of public green space	*A quarter acre*	0.25
		Half an acre	0.5
		One acre	1
		Five acres	5
Commute	Commute mode and time to work/school	*Car only, more than 40 min*	0
		Car only, within 40 min	1
		Public transportation (e.g., transit, bus) within 40 min	2
		Public transportation (e.g., transit, bus) within 30 min	3
		Biking within 20 min	4
		Walking within 15 min	5
School quality	Great school rating	*Low*	0
		Middle	0.5
		High	1
Transit	Walking distance to transit station	*Less than 10 minutes*	1
		Less than 20 minutes	0.5
		More than 20 minutes	0
Increase in price	Increase in price (or rent) as compared to the budget (%)	*-20*	-0.2
		-10	-0.1
		0	0
		+10	0.1
		+20	0.2

5.2.2 Latent-Class Residential Community Choice Model

In the survey, respondents were asked to provide the best and worst choices in each choice set. As compared to a traditional best choice experiment, the best-worst choice experiment significantly enhances data quantity/quality without much extra response effort. The best-worst choice data also has a technical advantage that provides a reference attribute level (i.e., a certain level of one attribute that occurs most often in all worst choices) that allows comparison of utilities across all levels of all attributes.[108]

The best-worst choice modeling is built on a sequential choice process, which assumes people first select the best option out of the choice set and second select the worst option out of the remaining alternatives. The probability of one alternative being chosen as the best option is determined by Eq. 5.1.

$$P(y_{it} = m \mid x) = \frac{\exp(\mathrm{U}_{m|x}^{t})}{\sum_{m'=1}^{M} \exp(\mathrm{U}_{m'|x}^{t})} \tag{5.1}$$

where, $U_{m|x}^{t}$ denotes the utility of the alternative *m* in choice set *t* of individual *i* belonging to class *x*.

The probability of one alternative being chosen as the worst option is determined by Eq. 5.2.

$$P(y_{it} = m \mid x) = \frac{\exp(-1 \bullet \mathrm{U}_{m|x}^{t})}{\sum_{m' \in A_{it}} \exp(-1 \bullet \mathrm{U}_{m'|x}^{t})} \tag{5.2}$$

where, A_{it} are the set of remaining alternatives of individual *i* excluding the best option in scenario *t*.

The value of $U_{m|x}^{t}$ is determined by Eq. 5.3 and the definition of variables are listed in Table 5.1. All the regression coefficients are class-specific.

$$\begin{aligned}U_{m|x} &= \beta_{0,x} + \beta_{1,x} \times \text{House Design} + \beta_{2,x} \times \text{Increase in Price} + \beta_{3,x} \times \text{Green Building} \\ &+ \beta_{4,x} \times \text{Accessibility} + \beta_{5,x} \times \text{Green space} + \beta_{6,x} \times \text{Public LID} + \beta_{7,x} \times \text{Private LID} \\ &+ \beta_{8,x} \times \text{School quality} + \beta_{9,x} \times \text{Commute} + \beta_{10,x} \times \text{Transit}\end{aligned} \tag{5.3}$$

The modeling of class membership is built on individual's socioeconomic characteristics and personal attitudes on LID and TOD. The variables are summarized in Table 5.2. I used Latent Gold Choice Software and Maximum Likelihood Method to run the estimation of the latent-class residential community choice model.[95]

One of the important research questions in this chapter is to figure out the market potential of LID and TOD. With the latent-class choice modeling (Eqs. 5.1 and 5.3), I evaluate the impact of an increase in housing price on the adoption of LID and TOD. Model results show the change in probability of individuals choosing the apartments with LID and TOD versus an alternative without these two features given the increase in housing price of the apartments with LID and TOD. Similarly, results will show the change in probability of individuals choosing single-family houses with LID versus choosing the alternative without LID given the increase in housing price of houses with LID.

Table 5.2. Variables and values for class membership modeling.

Variables	Definition and Value Assigned to Run Class Membership Modeling
Time to complete	The time each respondent spends completing the survey
TOD	Whether people are willing to ride public transits instead of driving the car to work if both take the same amount of time: Yes, 1; Probably Yes: 0.67; Probably No: 0.33; No, 0;
LID	Whether people are willing to pay more for low-impact development: Yes,1; Probably Yes: 0.67; Probably No: 0.33; No, 0;
Unit in structure	Single-family house: 1 Non single-family house (e.g., apartments, row house): 0
Kids	The presence of people under 18 years old: Yes, 1; No, 0;
Grouping rent	Rent the place and share with more than 3 people without no kids: Yes, 1; No, 0;
Education	Some high school & High school graduate: 0 Some college, no degree & Associates degree: 1 Bachelor degree & Graduate degree: 2
Income	$0-$49,999: 0 $50,000-$74,999: 1 $75,000-$99,999: 2 $100,000-$149,999: 3 $150,000 and up: 4
Employed	Employed: 1 Non-employed: 0
Age	18 to 24: 1 25 to 34: 2 35 to 44: 3 45 to 54: 4 55 to 64: 5 66 to 74: 6
Ethnicity	Black or African American: 1 White/Caucasian: -1 Others (e.g., Asian or Pacific Islander): 0
People in the house	Number of people in the household
Sex	Male: 1 Female: 0
Non work travel	Miles traveled per week for shopping or entertainment
Commute time	Commute time to work Less than 30 minutes: 0 More than 30 minutes and: 1

5.2.3 Agent-based Market Diffusion Model

The purpose of the market diffusion model is to predict the adoption of more compact development in the metro Atlanta in the next 20 years from 2014 to 2034. The diffusion model follows the same basic demand and supply mechanism of the diffusion model presented in Chapter 4. In year *t*, the probability ($P_{t,a}$) of an individual home buyer purchasing a new apartment home is determined by Eq. 5.4:

$$
\begin{aligned}
P_{t,a} &= \frac{f_a \exp(U_a)}{f_a \exp(U_a) + f_s \exp(U_s)} \\
&= \frac{f_a}{f_a + f_s \times \dfrac{\exp(U_s)}{\exp(U_a)}} \\
&= \frac{f_s}{f_a + f_s \times (\dfrac{\exp(U_s) + \exp(U_a)}{\exp(U_a)} - 1)} \\
&= \frac{f_a}{f_a + f_s \times (\sum_{i=1}^{4} P_i \dfrac{1}{P_{a|i}} - 1)}
\end{aligned}
\tag{5.4}
$$

where, f_a , f_s is the share of new apartment homes and new single-family houses in the housing supply market, respectively; U_a , U_s is the utility of living in an apartment and a single-family house; P_i is the probability of the individual belonging to the class *i*; and $P_{a|i}$ is the probability of choosing an apartment given class *i*.

Accordingly, the sale of new apartment homes in year *t* ($Sale_{t,a}$) is calculated as follows (Eq. 5.5):

$$
Sale_{t,a} = \min(N_t \times P_{t,a}, S_{t,a}) \tag{5.5}
$$

where, N_t is the number of home buyers in year *t*; $S_{t,a}$ is the supply of new apartment homes in year *t*. $N_t \times P_{t,a}$ is the demand for new apartment homes in year *t* ($D_{t,a}$). Our previous diffusion model only predicted the demand for more compact development from new households (NH_t). The new diffusion model here also considers the demand for more compact development from the relocation of existing single-family households ($RSFH_t$). However, I only consider the relocation of existing single-family households who settled in the metro Atlanta before 2013 because the relocation of this group from old single-family houses to new apartments generates the demand for new apartments. At the same time, to keep the model simple, the diffusion model does not include the relocation of new households who settle down after 2013 and the second-time relocation of existing single-family households who moved once between 2014 and 2034.

The demand and sales of new single-family in year *t* ($D_{t,s}$, $Sale_{t,s}$) is calculated as follows (Eq. 5.6 and 5.7):

$$D_{t,s} = \max(S_t - \min(NH_t \times P_{t,a}, Sale_{t,a}) - SF_{t,resale}, 0) \tag{5.6}$$

$$Sale_{t,s} = \min(D_{t,s}, S_{t,s}) \tag{5.7}$$

where, S_t is the supply of new apartment homes and new single-family houses in year *t*, which equals the number of new households in year *t* (NH_t); $NH_t \times P_{t,a}$ is the demand of new apartment homes from new households in year *t;* $S_{t,s}$ is the supply of new single-family houses in year *t*; $SF_{resale,t}$ is old single-family houses sold by the existing single-family households moving to new apartments in year *t* (Eq. 5.8). I assume no demolition of old single-family houses so that the number of old single-family houses for resale equals the number of existing single-family households who move to new apartments.

$$SF_{t,resale} = \min(Sale_{t,a} - P_{t,a} \times NH_t, P_{t,a} \times RSFH_t) \tag{5.8}$$

The supply of new apartments and new single-family houses is calculated by Eq. 5.9 and 5.10.

$$S_{t+1,a} = \max(NH_{t+1} \times \frac{D_{t,a}}{(D_{t,a} + D_{t,s})}, S_{t,a} - Sale_{t,a}) \tag{5.9}$$

$$S_{t+1,s} = \max(NH_{t+1} - S_{t+1,a}, S_{t,s} - Sale_{t,s}) \tag{5.10}$$

The starting conditions of the diffusion model include: (1) NH_t constantly equals 29,038 assuming the stable increase of new households from 2014 to 2034 in the metro Atlanta;[109] (2) the number of existing single-family households to relocate ($RSFH_t$) in 2014 is 231,370, which is 12% of total households in 2013 (see Appendix C: Mover Rate in the Metro Atlanta); and $RSFH_{t+1} = 0.88 \times RSFH_t$ because in year *t+1* the remaining existing households who settled down in the metro Atlanta before 2013 is 12% less than that in year *t* after the relocation; (3) the total supply of new apartment homes and new single-family houses (S_t) equals 29,038 in year *t*, the same number as new households in year *t* (NH_t), for which 92% are single-family houses and 8% in apartments (see Appendix D: Housing Types in the Metro Atlanta).

The fraction of new apartments sold (f_a^T) up to year *T* is emergent as follows (Eq. 5.11):

$$f_s^T = \frac{\sum_{t=2014}^{T} Sale_{t,a}}{\sum_{t=2014}^{T} Sale_{t,a} + \sum_{t=2014}^{T} Sale_{t,s}} \tag{5.11}$$

The f_a^T value shows the time-dependent diffusion curves (i.e., adoption rate) of new apartments. I use the results for f_s^T to assess whether LID and TOD for apartment communities can contribute significantly to less sprawling land development in the metro Atlanta.

5.2.4 Analysis of Policy for LID Using the Market Diffusion Model

To evaluate the impact of the "home-based LID policy" and "community-based LID policy" on the adoption of more compact development, the market diffusion model includes the effects of LID on a home buyer's choice between apartment homes versus single-family houses (Eqs. 5.4 and 5.5). The effects of LID include the utility improvement because of amenities (e.g., harvested rainwater, created green space) provided by LID and the increase in price (i.e., the difference in cost paid by the developers between LID and conventional underground detention tanks as compared to the sale price). Conventional underground detention tanks also provide the required storm water control. However, unlike LID, detentions tanks cannot provide amenities that can increase the utility. The implementation of LID (i.e., green roof, rain garden, porous pavement and native vegetation) and onsite wastewater reclamation on apartments and public open spaces leads to 0.9% increase in apartment price. The implementation of LID (i.e., rainwater harvesting, rain garden, porous pavement and native vegetation) on individual lot (i.e., house and private yard) leads to 1.41% decrease in house price. House price decreases by 1.76% using a community-based LID for single-family house community (see Appendix E: Cost of Low-Impact Development). It is cheaper to use LID than to use underground tanks to control storm water.

TOD features are provided to make apartment homes more attractive, assuming that the government leads the efforts of investing the public transit, which promotes the mobility and more compact development. In contrast, the single-family house community has no TOD features because land use density is too low to make the transit system profitable.

5.2.5 Environmental Impact Assessment

Given the adoption rate of more compact development, I evaluated the environmental benefits of implementing LID and TOD. I followed the life-cycle environmental and economic assessment of transit-oriented neighborhood designs reported by Chester, et al.[110] The details of transit-oriented neighborhood and conventional suburban community for 3,200 housing units are shown in Table 5.3. The annualized life-cycle carbon emissions of the transit-oriented neighborhood are 0.033 million tons/year on average while the conventional suburban community emits 0.053 million tons/year. However, the comparison of carbon emissions between the transit-oriented neighborhood and the conventional suburban community does not include the direct impacts of LID on carbon emissions of water, wastewater and sewer systems. Previous study showed that the emissions of the sewer network coupling with detention tanks are 0.88 tons/year/acre of drainage area. On the other hand, decentralized green infrastructure technologies (i.e., LID) can reduce the carbon emissions of the sewer network to 0.20 tons/year/acre of drainage area.[111] Although carbon emissions of the sewer network are significantly decreased using green infrastructure strategies, the reduction in carbon emissions is 3% of that resulting from more compact development (e.g., savings in infrastructures and vehicle miles traveled). So I assume the impact of

LID on the reduction in carbon emissions can be ignored. However, it should be noted that LID does contribute to the reduction in carbon emission indirectly through its impact on the adoption of more compact development.

I calculated the carbon emissions of having more compact development using a simple method. I first determined the total number of transit-oriented neighborhoods and conventional suburban communities (including new apartments and single-family houses) that were built between 2014 and 2034 for each of the three scenarios. Then the carbon emissions were calculated as the sum of the carbon emissions of transit-oriented neighborhoods and conventional suburban communities.

Table 5.3. Transit-oriented neighborhood and conventional suburban community.[110]

	Total Land Use (acres)	Residential Single-family Dwelling Units	Residential Multi-family Dwelling Units	Total Commercial Space (million ft^2)	Total Park & Community Space (acres)
Transit-oriented Neighborhood: Multi-family Apartments Mixed Use Infill	74	53	3,120	2.9	7
Conventional Suburban community: Suburban Single-family Homes & Commercial Structures	630	3,200	0	2.9	7

5.3 Results

5.3.1 Summary of Respondent's Characteristics

There are 764 useful responses from total 811 responses obtained from Mechanical Turk. Only 6% of respondents did not follow the survey instruction, including those who did not complete the survey and those who gave the same answers to the choice of best and worst communities. A summary of socioeconomic characteristics of these 764 respondents is provided in Table 5.4. Variables such as sex, household income, ethnicity, employment and presence of children are very similar when comparing the sample from Mechanical Turk and statistics in the Census of metropolitan Atlanta. However, the respondents on Mechanical Turk are younger and achieved a higher level of education. Also the majority of the respondents (66%) on Mechanical Turk rent the properties, which is significantly higher than in the Census. The proper treatment of this sample bias is critical to a reasonable estimation of the preferences. As discussed in Chapter 4, choice modeling methods such as multinomial logit model leads to incorrect estimation of the preference by treating the biased sample as one homogenous group to represent the population. Instead, the latent-class choice model enables the elimination of the overestimation/underestimation of preferences for community designs given the biased sample by using the classification of respondents and running the estimation separately for each class. The bias in the sample matters in terms of the distribution of classes in the sample on Mechanical Turk and the real population. To address this issue, I used the class membership function of the latent-class residential community choice model and the PUMS to estimate the correct distribution of classes in the metro Atlanta. The PUMS, which is considered an unbiased sample of individuals in the metro Atlanta, is a subsample of individual person and housing unit records (e.g., sex, education, and employment status) is available from American Community Survey (ACS).

Table 5.4. Summary of respondents on Mechanical Turk.

Social-economic variables	Categories	Value	U.S Census 2013
Sex	Male	49%	49%
	Female	51%	51%
Age	20-24	26%	9%
	25-34	46%	20%
	35-44	19%	21%
	45-54	6%	20%
	55 or older	3%	30%
Education	Some high school	1%	13%
	High school graduate	7%	25%
	Some college, no degree or associate's degree	38%	30%
	Bachelors or graduate degree	53%	32%
Household Income	$0-$24,999	13%	22%
	$25,000-$49,999	29%	24%
	$50,000-$74,999	25%	19%
	$75,000-$99,999	16%	12%
	$100,000-$149,999	13%	13%
	$150,000-$199,999	2%	5%
	$200,000 and up	2%	5%
Ethnicity	American Indian or Alaskan Native	3%	0%
	Asian or Pacific Islander	7%	5%
	Black or African American	24%	33%
	Hispanic or Latino	6%	11%
	White/Caucasian	64%	51%
Employment	Employed (including self-employed)	79%	60%
	Unemployed	6%	8%
	Not in labor force (i.e., retired, disable, and student)	15%	33%
Kids	Households with people under 18 years	35%	37%
Housing Tenure	Owner-occupied housing units	33%	64%
	Renter-occupied housing units	66%	36%
Unit in Structure	1-unit structures	42%	74%
	2-or-more-unit structures	56%	23%
	Mobile homes and all other types	2%	3%

5.3.2 Latent-class Residential Community Choice Modeling

I used 648 responses to estimate the latent-class residential community choice model. I selected four classes as the optimal number to represent the preference heterogeneity. Although the BIC of the four-class choice model is higher than five-or-more class choice model, the interpretation of classes is much clearer using the four classes. At the same time, there is no significant improvement in modeling accuracy in terms of percentage of choices that are modeled correctly as the number of classes is more than four (see Appendix F: Selection of the Number of Classes). Thus, I adopted the results of the four-class residential community choice model to describe the preferences of individuals in the metro Atlanta for LID, TOD and more compact development.

5.3.2.1 Preference of the Four Classes

Individual's preferences for different community design attributes are measured by the relative importance of these attributes in decision making.[95] The relative importance is a maximum effect of each attribute on utility (Eq. 5. 3) that is rescaled to sum to 1 across attributes within a latent class (Eqs. 5.12 and 5.13). Different ranking of the relative importance of the attributes in influencing decision making shows the preference heterogeneity of people living in the metro Atlanta. According to the ranking of different attributes, I named the four classes "compact", "sprawling", "school-dominant" and "price-sensitive". As shown in Figure 5.2, "Commute", "Accessibility" and "School quality" are the top three attributes for the "compact" class. The positive β associated with "Commute", "Accessibility" and "School quality" shows that "compact" class prefers the community that takes 15 minutes walking to work/school and 10 minutes walking for foods, shopping and entertainment, and has better school quality (Table 5.5). In contrast, the “sprawling” class considers “House design”, “Private LID” and “School quality” as the top three important attributes. In other words, the “sprawling” class prefers single-family houses, the implementation of LID on private yards and better schools. The “school dominant” class considers school quality to be the most important attribute in choosing where to live, while members of the “price-sensitive” class think the price is most important. Both “school-dominant” and “price-sensitive” classes prefer single-family houses over apartments.

$$\max eff_{xp} = \max(\beta a|_{xp}) - \min(\beta a|_{xp}) \tag{5.12}$$

$$\mathrm{rel}eff_{xp} = \frac{\max eff_{xp}}{\sum_{p} \max eff_{xp}} \tag{5.13}$$

where, $\max eff_{xp}$ is the maximum effect of attribute p for latent class x on the utility; α is a certain level of attribute p.

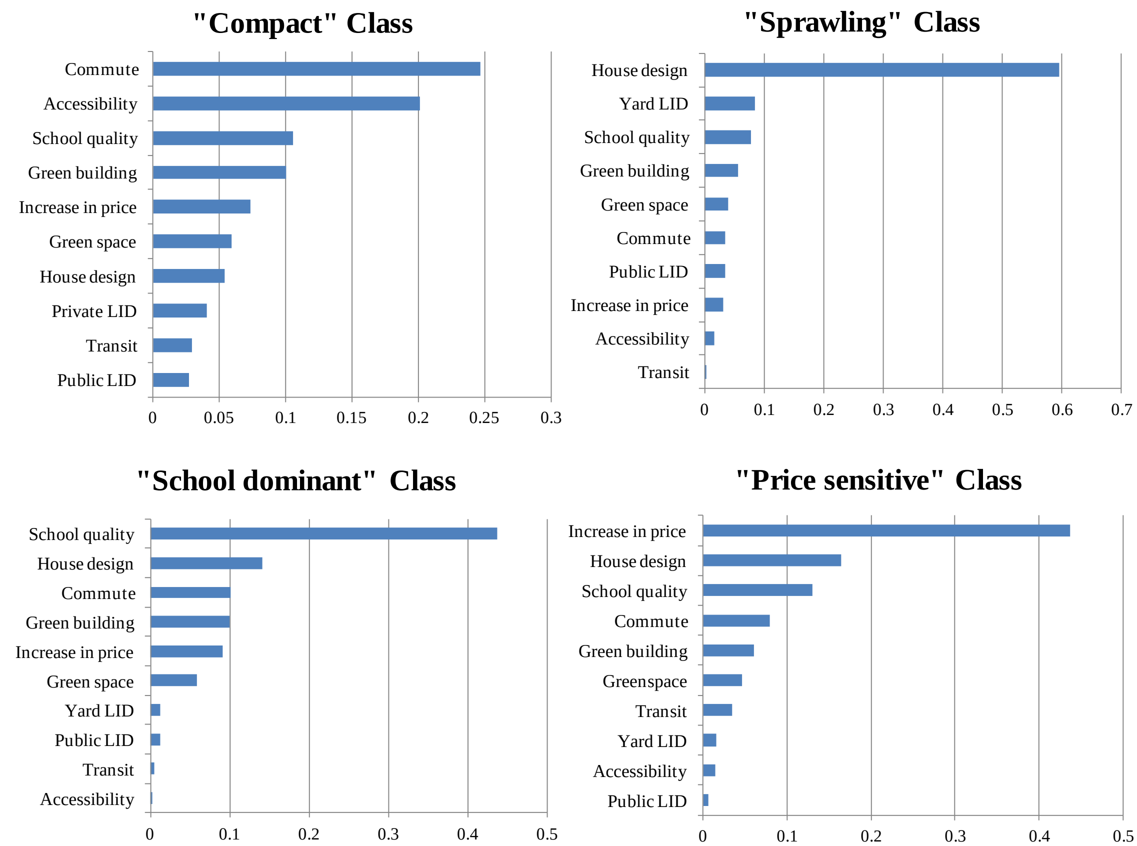


Figure 5.2. The relative importance of different attributes for the four classes.

To better distinguish the four classes, I compared the demand for the number of bedrooms, bathrooms and the size of housing area among the four classes. As shown in Figure 5.3, the "school-dominate" class need more bedrooms and bathrooms than the other three classes. This is because of the presence of children in the family of the "school-dominate" class. In terms of the housing area, the "sprawling" class looks for a larger housing area than other three classes. The "price-sensitive" class needs the smallest housing area. I also compared the budget for the living space of the four classes. I found that the average housing price that the "compact" class claims to afford is higher than the "sprawling" class. It turns out that people who are willing to live in more compact living spaces have the financial capacity to afford the amenities (e.g., accessibility, open space) associated with more compact development. The “price-sensitive” class requires a lower price or rent than the other three classes.

Figure 5.3. Demand for housing area, number of bedrooms and bathrooms, and the affordable price and rent of the four classes.

The impact of socioeconomic characteristics and personal attitudes on class membership is summarized in Table 5.5. People who currently live in single-family houses tend to be members of “sprawling” and “school-dominant” classes while people currently live in apartments are likely to be “compact” and “price-sensitive” classes. People with kids are most likely to belong to the “school-dominant” class and least likely to be the “compact” class. The “price-sensitive” class contains more people who currently live in a house/an apartment with more than 2 people and without kids, as compared to the other three classes do. Meanwhile, individuals who receive higher education (e.g., graduate degree) tend to be the “price-sensitive” class. I conclude that one of the major groups in the “price-sensitive” class is students because students tend to share a house/an apartment with more than 2 people without kids and have higher education. People with bachelor degree or less in the Mechanical Turk sample is unlikely to remain in schools as students, and correspondently unlikely to be the “price-sensitive” class. Instead, if an individual has less education, he/she is more likely to be the “sprawling” class. People with higher household income show a higher probability to be “school-dominant” and “compact” classes because of both classes look for more amenities near the communities. Unemployed people are less likely to be in the “sprawling” class, because they demand more community amenities (i.e., better school quality, higher accessibility) and cannot afford housing and transportation cost in suburban low-density developments.

Three personal attitude variables are adopted to run the class membership modeling and all the three variables have statistically significant impacts on class membership. The first personal attitude variable is “Time to complete”, which refers to the time respondents spent on the survey. People who spent more time on the survey tend to be “school-dominant” and “price-sensitive” classes. I conclude that people belonging to “school-dominant” and “price-sensitive” classes think more carefully in terms of the community selection. The second personal attitude variable is “TOD”, which represents people’s willingness to spend the same time on riding public transits instead of driving a car to work. People who said “yes” are most likely to be members of the “compact” class. In contrast, people who said “no” are most likely to be members of the “sprawling” class. The third personal attitude variable is “LID”, which represents people’s willingness to pay more for the LID on public open space or private yard. People who are unwilling to pay are more likely to be the "price-sensitive" class. Overall, the understanding of personal attitudes enables a better interpretation of people's preference and behavior of choosing where to live.

Table 5.5. Summary of four-class choice model estimates for community attributes, socioeconomic and attitudinal variables (Eq. 5.3).

Model for Best-Worst Choice						
	"Compact"	"Sprawling"	"School-dominate"	"Price-sensitive"	Overall	
R^2	0.065	0.416	0.384	0.258	0.217	
Community Design Attributes					p*	p(=)**
Constants	-0.197	-0.159	-0.284	0.051	0.000	0.049
HouseDesign						
16story	-0.037	-1.110	-0.446	-0.520	0.000	0.000
8story	0.012	-1.155	-0.180	-0.061		
4story	0.088	-0.506	0.016	0.043		
Rowhouse	0.055	-0.318	-0.158	-0.179		
Semidetached	-0.039	0.870	0.192	0.263		
Singlefamily	-0.078	2.219	0.577	0.455		
GreenBuilding						
None	-0.172	-0.140	-0.358	-0.186	0.000	0.000
GRWR	0.139	0.175	-0.007	0.014		
RWH	0.033	-0.035	0.366	0.172		
Price	-0.567	-0.435	-1.660	-6.490	0.000	0.000
Accessibility	0.624	0.088	-0.016	0.090	0.000	0.000
Greenspace	0.037	0.044	0.085	0.056	0.000	0.080
PublicLID	0.084	0.192	0.086	-0.042	0.000	0.070
PrivateLID	0.126	0.480	0.093	0.098	0.000	0.000
Commute	0.153	0.039	0.147	0.095	0.000	0.000
School	0.328	0.440	3.184	0.773	0.000	0.000
Transit	0.092	-0.018	-0.032	0.206	0.002	0.066

Model for Classes					
	"Compact"	"Sprawling"	"School-dominant"	"Price-sensitive"	p-value
Intercept	1.403	0.616	-1.651	-0.368	0.007
Covariates					
Timetocomplete	-0.024	-0.032	0.027	0.029	0.000
TOD	0.956	-1.108	0.260	-0.108	0.000
LID	0.561	0.615	-0.074	-1.101	0.024
Unitinstructure	-0.601	0.382	0.516	-0.298	0.000

Kids	-1.215	-0.368	0.960	0.624	0.000
Groupingrent	-0.072	-0.740	-0.046	0.858	0.049
Education	0.071	-0.385	-0.129	0.443	0.027
Income	0.105	-0.135	0.222	-0.192	0.017
Employed	-0.346	0.914	-0.258	-0.310	0.010
Age	-0.051	0.188	-0.015	-0.122	0.096
Ethnicity	0.103	0.036	-0.032	-0.108	0.660
Peopleinthehouse	0.021	0.064	0.081	-0.166	0.530
Sex	-0.042	0.012	-0.077	0.107	0.950
Nonworktravel	-0.001	-0.001	-0.001	0.003	0.290
Commutetime	-0.063	0.123	0.214	-0.274	0.720

* The p value shows the significance level of the coefficients. The p larger than 0.05 associated with a certain attribute indicates no significant effect of the attribute on individual utility.

** The p (=) value shows the significance level of the difference in coefficients among the four classes. The p (=) larger than 0.05 associated with a certain attribute indicates no significant difference in preference for this attributes among the four classes.

5.3.2.2 Spatial Distribution of the Four Classes in the Metro Atlanta

Given the bias of sampling, the ratios of the four classes in the sample cannot properly reflect the true percentages of the four classes in the metro Atlanta. In order to estimate the ratios of the four classes correctly, I used the PUMS data to calculate the probability of individuals belonging to each class using the estimated class membership modeling. The percentage of each class is the average probability of individuals belonging to this class. It should be noticed that the PUMS does not provide any personal attitude variables, which may still lead to the biased estimation of the percentage of the four classes.

Results show that the percentage of the “compact”, “sprawling”, “school-dominant” and “price-sensitive” classes is 22%, 62%, 9% and 7%, respectively. The “sprawling” class is the dominant class, which imposes a great challenge to promote more compact development in the metro Atlanta. The PUMS provides the locations of sample individuals in the Public Use Microdata Area (PUMA) level. PUMAs are non-overlapping areas that partition each state into areas containing about 100,000 residents. Ratios of the four classes for each PUMA are presented on the PUMA map that covers the metro Atlanta. As shown in Figure 5.4, a higher percentage of the “compact” class is found in the central urban area of the metro Atlanta while a higher percentage of the “sprawling” class live in the suburban areas. Higher percentage of “school-dominant” class is found in East Cobb, North Fulton, part of Gwinnet, south Forsyth and Fayette County. These areas have the best schools in terms of school test scores.[112] The percentage of the “price-sensitive” class is higher in places where the household income is lower or where students are living. Spatial visualization indicates that where individuals are living are the areas that fit their preferences.

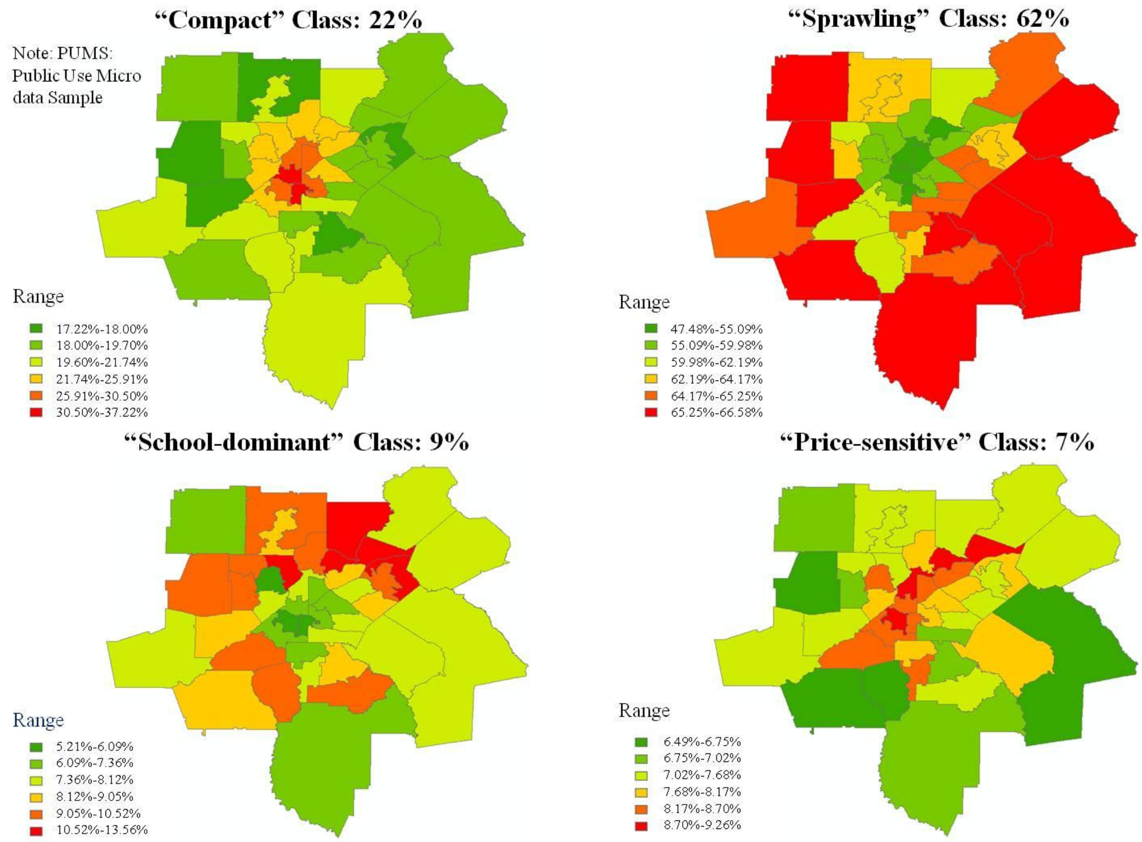


Figure 5.4. Spatial distribution of the four classes in the metro Atlanta.

<u>5.3.2.3 Validation of Latent-class Choice Model</u>

The validation of the estimated latent-class residential community choice model is critical to understand the tradeoff between the increase in housing price and the adoption of LID and TOD, and to provide a reliable decision making module that feeds into an agent-based model to predict the future land use pattern. I used 648 responses to develop the choice model and kept 116 responses for validation. I compared the predicted distribution to the observed distribution of the times of each choice to be selected as the best alternative with the real value in each choice set (Figure 5.5). I adopted a two-step approach for the validation, which includes a Chi-square test and sample deviation (SD). The Chi-square test is to distinguish whether the difference between the predicted and actual distribution is significant. In case of a certain choice set where the difference is significant, the SD measures the relative error between the predicted number of people for each option to be chosen as the best and the actual value (Eq. 5.14). The Chi-square test shows no significant difference between the predicted and actual distribution in the 6 out of 14 choice sets. Among the rest 8 choice sets, the maximum SD is 17%. These results indicate the latent-class residential choice model can be trusted in some degree.

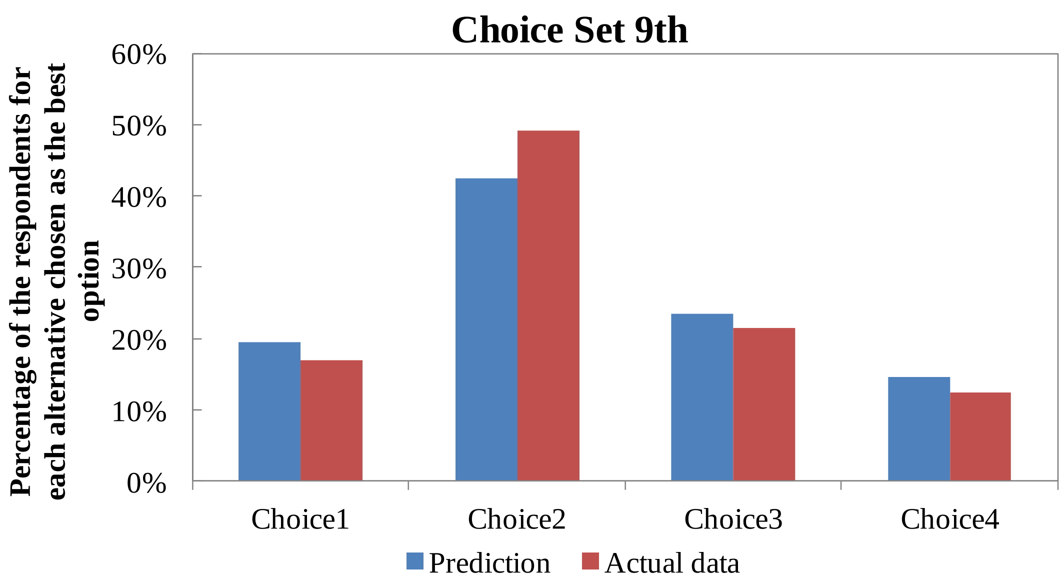


Figure 5.5. Comparison between predicted percentages of the respondents for each alternative chosen as the best option and the actual percentages (use choice set 9th as an example).

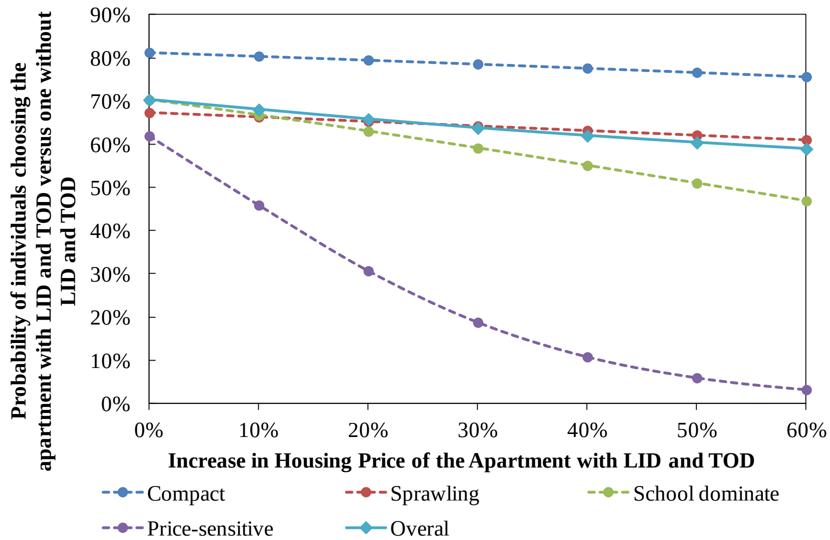
$$SD_j = \sqrt{\frac{\sum_{i=1}^{N}\left[\Pr ediction_{i,j} - Actual_{i,j}\right]^2}{N-1}} \tag{5.14}$$

where, SD_j is the sample deviation of choice set j^{th}; $\mathrm{Precition}_{i,j}$ is predicted percentage of respondents who chose alternative i as the best option in choice set j^{th}, $\mathrm{Actual}_{i,j}$ is actual percentage of respondents who chose alterative *i* as the best option in choice set j^{th}, and N is the number of options in each choice set (*N*=4).

5.3.2.4 Impact of Increase in Price on the Adoption of LID and TOD

Given the latent-class residential choice decision making model, I studied the impact of price increase on the adoption of LID and TOD. For a 4-story apartment, LID includes the installation of green roof and wastewater reclamation in the building and the investment of rain garden, native plants and porous pavement on public open space. TOD means the less than 10 minutes walking for food, entertainment and recreation, and less than 30 minutes by public transit to work. I found that the probability of individuals choosing an apartment, which has LID and TOD features over the one without these two features, decreases slightly as the price increases except for the “price-sensitive” class (Figure 5.6).

For single-family homes, I only studied the market potential of LID because the density is too low to make TOD investment profitable. LID for single-family houses specifically refers to rainwater harvesting in the building and rain garden, native plants and porous pavement on private yard. I found that the probability of individuals choosing the single-family house with LID over the one without LID slightly decrease as the housing price increases except for the “price-sensitive” class. Overall, the weak negative impact of increase in price on the adoption of LID and TOD indicate a low risk of investing LID and TOD in the metro Atlanta for real estate developers and city government.



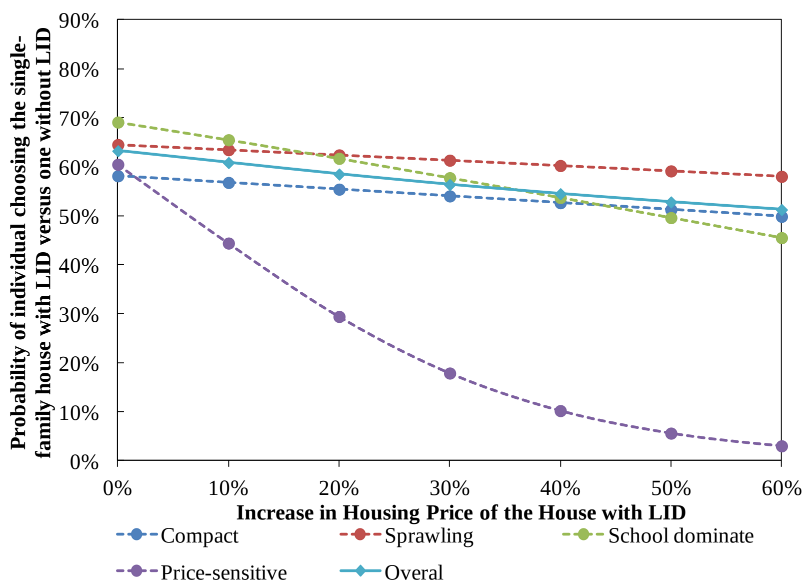


Figure 5.6. The impact of increase in housing price of the apartment with LID and TOD on the adoption of the apartment with LID and TOD versus one without LID and TOD (up); the impact of increase in housing price of the house with LID on the adoption of the single-family house with LID versus one without LID (bottom).

5.3.3 Market Diffusion of More Compact Development with LID Policy Intervention

I evaluated the implementation of LID and TOD in the metro Atlanta on future land use pattern using the market diffusion model. The agent-based market diffusion model predicted the adoption of new 4-story apartments in three scenarios (Figure 5.7).

First, in the BAU scenario, the share of new 4-story apartment units sold from 2014 to 2018 increases slightly to 10%. It indicates that there is an undersupply of high-density communities in the metro Atlanta even in the BAU. After that, the share of total new 4-story apartment units sold starts declining because the demand for new 4-story apartment is not sustained, because the annual number of existing single-family households that choose to relocate decreases ($RSFH_t$). In the "home-based LID" scenario, the share of total new 4-story apartment units sold in new home sales increases in the first 8 years from 2014 to 2021. The increase is driven by the higher demand for new 4-story apartment homes with LID and TOD features. But the increase is not sustained after 2021. By the end of 2034, the single-family houses still dominates new residential development. The major reason is that the implementation of LID for single-family houses (including rainwater harvesting and rain garden, porous pavement and native vegetation for private yards) leads to a significant increase in utility for single-family houses. The improvement in single family house utility offsets the improvement in utility of the apartments from LID and TOD. In other words, the improvement in utility of the apartments is not enough to create a sustained demand for new 4-story apartments. In contrast, the share of total new 4-story apartment units sold increases consistently from 2014 to 2034 in the "community-based LID" scenario. By switching the requirement of treating the 1.0 inch stormwater runoff on individual lots to the community-based treatment using LID, we reduce the increase of utility for single-family houses. In addition, part of the demand for new single-family houses is met by old single-family houses, which are vacated as existing single-family households relocate to new 4-story apartments. As a result, the supply of new single-family houses in the house market decreases further, leading to a higher probability of homebuyer's considering and adopting new apartments. Overall, I conclude that the implementation of LID and TOD can contribute to the promotion of more compact development. Meanwhile, the "home-based LID policy" that emphasizes individual single-family home needs to treat its first 1.0 inch of runoff independently should be switched to the "community-based LID policy" that requires new single-family homes to manage the first 1.0 inch of runoff on the community basis.

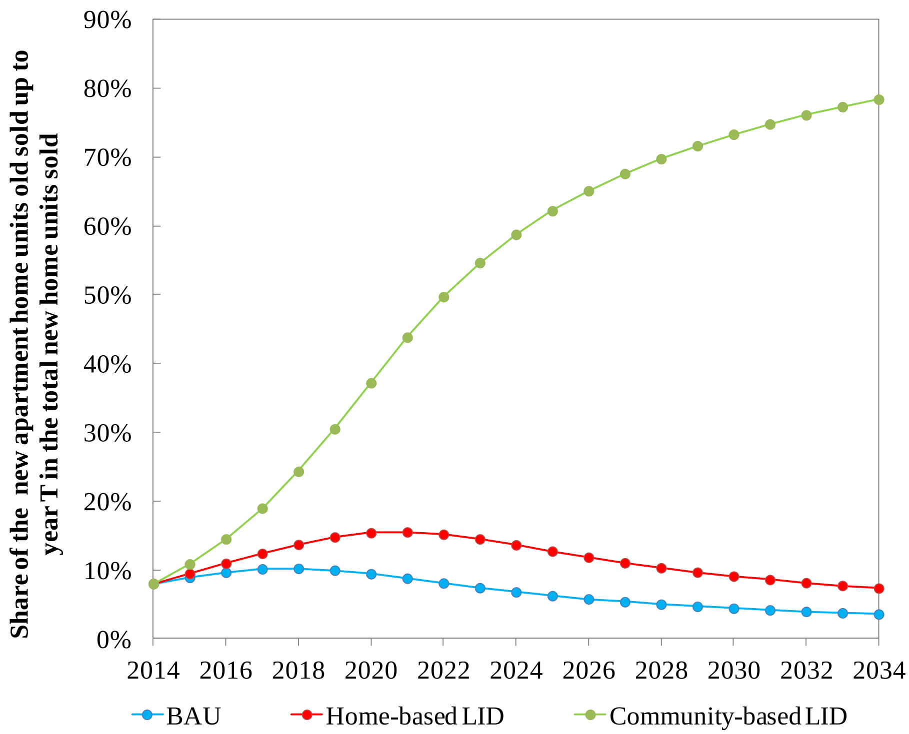


Figure 5.7. Share of the 4-story apartment communities in newly built home units up to year *T*.

5.3.4 Environmental Impacts of More Compact Development

As shown in Figure 5.8, there is no significant difference in carbon emissions between BAU and home-based LID scenario. It is worth noting that apartments have no TOD feature in the BAU scenario. However, given the 2.6% of total housing were apartments, I used the carbon emissions for transit-oriented apartment neighborhoods for BAU and ignored the small error. In contrast, there is 28% of carbon emission reduction in the community-based LID scenario as compared to BAU. The carbon emission data do not accurately reflect the constructions and operations of new development in the metro Atlanta. However, these results show the potential for carbon emission reductions that result from more compact living space, LID and TOD.

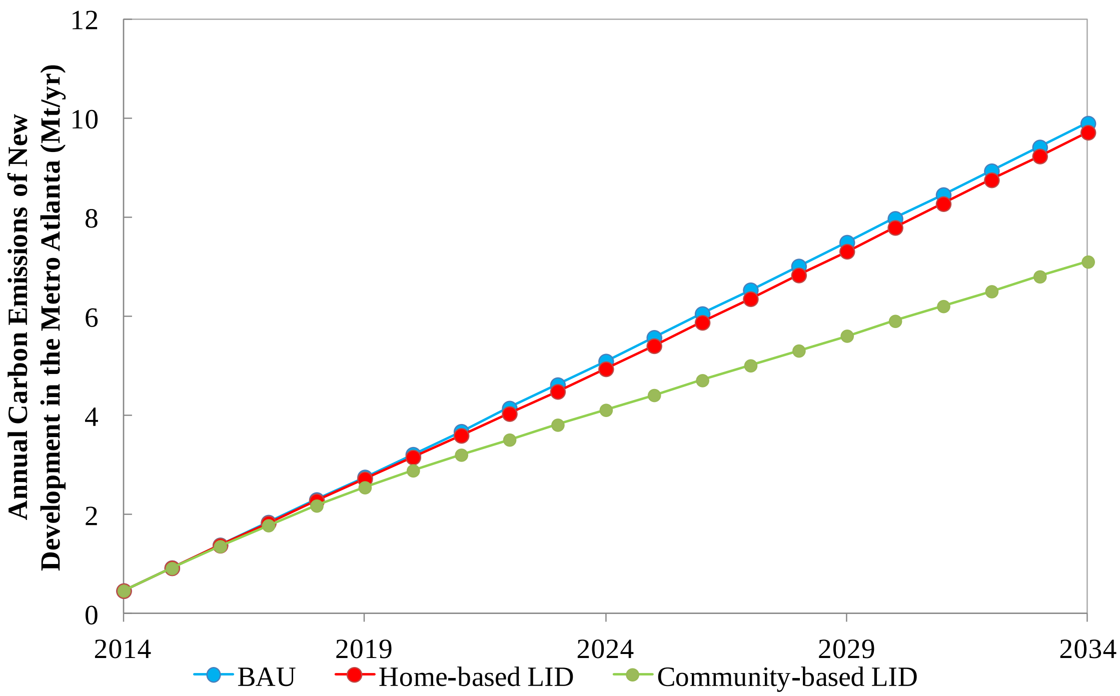


Figure 5.8. Annualized life-cycle carbon emissions of new development in the metro Atlanta from 2014 to 2034 under three scenarios.

5.4 Discussion

In summary, a survey was developed to measure metro Atlanta residents' preference for community designs. Using the responses collected from Mechanical Turk, a latent-class residential community choice model was constructed that includes the impacts of different community design attributes on the choice decision. Results show substantial heterogeneity in preference among residents in the metro Atlanta. Four classes were identified and named “compact”, “sprawling”, “school-dominant” and “price-sensitive”. Preferences for house design, accessibility, school quality and other community features varies among these four classes. The “sprawling” class who prefer single family houses more than other features is the largest class that 62% of people belong to in the metro Atlanta. This imposes a great challenge of promoting more compact development in the metro Atlanta in the future.

The analysis of the impact of increase in housing price on the adoption of LID and TOD shows a low risk of investing LID and TOD in the metro Atlanta. Residents are willing to adopt the community with LID and TOD as compared to the corresponding one without LID and TOD. Considering the contribution of LID and TOD to sustainable water, transportation and land use, metro Atlanta has a great potential to be more sustainable.

The results from the agent-based market diffusion model show that a proper policy design for LID is critical to the promotion of more compact development. The revised ordinance that requires single-family houses to implement LID on their lots may not lead to a higher adoption of more compact development. Instead, if single-family houses are required to collaboratively manage the stormwater runoff with LID in the community, this may lead to a higher adoption of more compact development. The benefits of carbon emission reduction from more compact development indeed support the necessity of reconsidering the policy requirement on LID in the metro Atlanta.

The modeling of agent’s behaviors is critical to the development of a reliable agent-based model that predicts adoption of more sustainable infrastructures. To address this, a survey was developed and the survey responses were used to construct a latent-class residential community choice model with the survey responses. Although the choice model may miss some variables (e.g., marital status, job types) for class memberships, it is a step forward. In this study, 6 out of 14 choice sets showed no statistical differences between predicted and actual times of each alternatives to chosen as the best option. Among the remaining 8 choice sets, the maximum SD is 17%. To improve the accuracy of the residential community choice model, additional household decision making factors need to be identified through the further mining of existing literature on choice models.

The most important accomplishment, of this present study, is the understanding gained of metro Atlanta residents' preferences for community designs and the development of a latent-class residential community choice model that reflects these preferences. The agent-based market diffusion model and the environmental impact assessment illustrate a more advanced application of the latent-class residential community choice model. The approach described in this thesis demonstrates an integrated framework which feeds the calibrated decision model to an agent-based model for predicting emergent land use patterns. This framework can be used to manage the sustainability of urban system, i.e., increasing the adoption of more sustainable infrastructures. Adoption increases by providing the attributes that stake holders want and developing policies that drive their adoption. However, both the agent-based market diffusion model and environmental impact assessment developed in this thesis need to be expanded to include additional components in order to improve further on their explanatory/predictive power. For example, the agent-based market diffusion model does not account for other important processes such as property bidding among homebuyers, location selection for investing new communities and business offices. The agent-based market diffusion model also does not produce the 2D spatial information of new development in the metro Atlanta. Environmental impact assessments for metro Atlanta require more effort developed to estimating travel vehicle miles traveled, water treatment and conveyance cost, building energy, and material consumptions for different spatial land use patterns.

Lastly, Mechanical Turk is a cost-effective solution to engage with the cohorts and collect the data for decision modeling. Only 6% of respondents dropped out of the survey or gave wrong answers to the questions. On average, each respondent spent 16 minutes on the survey, which is about 45 seconds for each choice set plus about 6 minutes for other questions (e.g., income, education). Although bias exists in the sample, the latent-class choice model can help avoid the overestimation or underestimation of people's preferences for the attributes of interests by accounting for heterogeneity in preference. Another benefit of using Mechanical Turk in the area of understanding human preference is the back and forth communication with the cohorts without much effort. It also allows one to refine the survey from the feedback of respondents. Users of Mechanical Turk can also explore the demand for other types of more sustainable infrastructures. Furthermore, the cohort on Mechanical Turk can serve as stakeholder advisory board to validate predictions of the ABM.

5.5 Conclusion

In this study, I investigated the preference of metro Atlanta residents for LID and TOD using survey data and a latent-class choice model. Results show substantial heterogeneity in preference for community designs among the residents in the metro

Atlanta. It turns out that LID and TOD have a great potential in the metro Atlanta, as the increase in housing price is found to have a weak negative impact on the adoption of LID and TOD. Further, I integrated the individual residential community choice simulation into an agent-based market diffusion model to predict the emergent land use pattern and explore policies that can drive the adoption of more compact development. Results suggest that the current policy that requires single-family houses to implement LID based on individual sites should be switched to one that requires community-based LID for single-family houses. Such a policy switch will lead to a higher adoption of apartment homes with LID and TOD. Lastly, I estimated that a 28% carbon emissions reduction from more compact development driven by LID and TOD.

CHAPTER 6

CONCLUSIONS AND FUTURE WORK

Urban systems are complex and adaptive. Understanding and modeling the complexity of urban systems is critical to the development and improvement of sustainable urban infrastructures. This dissertation describes an integrated methodological framework that targets understanding and modeling this complexity. This framework starts from the bottom level understanding of human preference for more sustainable infrastructures (i.e., LID and TOD) and the impact of more sustainable infrastructures on decision making (i.e., the adoption of more compact living spaces). Then, behavioral and decision making models are fed into an agent-based model that describes the interactions of the urban system. By running the ABM with the intervention of different policies, emergent properties (e.g., land use change, tax revenues, and water consumption) show up differently to inform stakeholders' decision making. A life-cycle assessment on emergent urban growth further provides a more comprehensive evaluation of sustainability.

Based on the progress achieved in this dissertation, future work is recommended below to improve this modeling framework as a practical method of modeling the complexity of urban system:

6.1 Development of an Integrated Platform to Match Demand with Supply

Future work should focus on developing an integrated platform that projects the demand for urban infrastructures and meets the demand with more sustainable policy options. The foundation of the integrated platform to project the demand for urban infrastructures is the interrelated land use-transportation decisions in terms of where to live, and where to work, shop and commute. Given the projected demand for urban infrastructures, the platform developed in this thesis will support the design and visualization of infrastructures the city might build. For developed areas, the inventories of existing infrastructures should be fully developed in support of the environmental impact assessments.

The integrated platform should be adaptive. First of all, the platform should allow for the addition of the impacts of more sustainable infrastructures on land use decisions and traffic behavior, which will ultimately change the form of the city. Second, the platform should allow for the connection with infrastructure analysis software geared to the consumption of water, energy, transportation and buildings. As a result, stakeholders can better understand how the infrastructure systems will perform as a whole system. Third, the platform should allow for the connection with impact analysis models such as urban air quality, heat island effect and disaster analysis. Overall, the adaptability of the platform should be achieved and maintained, with the ultimate goal of generating a full description of how a city functions.

Chapter 5 describes the initial efforts at developing such an integrated platform, which involved the modeling of individual preference and choice, the development of an agent-based model to predict the demand and the assessment of environmental impacts. The connection of the agent-based model to an environmental impact assessment will be achieved in future work.

Selection and integration of more sustainable infrastructures as an input of the integrated platform should be addressed as well to develop more sustainable scenarios. In the future, I will look at the thresholds at which higher density TOD limits the applicability of certain LID strategies and vice versa at what low densities is TOD not feasible but more aggressive LID works. Future work should dig deeper into the impacts of alternative transportation modes (e.g., bus rapid transit, light rail and bikes) and compare the costs of those facilities with the densities needed.

6.2 Big Data Analytics for Uncovering the Interdependences between Infrastructures and Socioeconomic Environment

Decision makings related to infrastructures (e.g., housing location choice influenced by transportation accessibility) determines the macro level interdependences between infrastructures and socioeconomic environment. In this dissertation, I used Mechanical Turk to gather data to understand the demand for LID and TOD in the metro Atlanta. Another alternative is big data analytics. Some big data sources, such as comments on News, Twitter, and Flicker provide the opportunities to measure people's preference for amenities, traveling and living style. A challenge in analyzing these big data, Twitter in particular, is how to appropriately extract the information about particular design attributes and consumer preferences from the messages. Some other data sources, such as GPS and sensors for energy and water consumption provide opportunities to investigate behavioral adaptation to more sustainable infrastructures here (e.g., electric vehicle charging behavior, energy/water use behavior).

6.3 Sustainability Metrics for Public Communication

The third piece is about the development of sustainability metrics, which allows the communication with stakeholders and informs the decision making of stakeholders. The metrics should include both universally applicable metrics for cities and the customized metrics for particular stakeholders (e.g., for utility companies, local communities, and governments). To develop the customized metrics, priorities in the mind of different stakeholders should be understood first.

Finally, another purpose behind establishing the sustainability metrics is to help validate prediction models of complex adaptive urban system as well as to monitor how well the city and the infrastructure systems are performing.

APPENDIX A

STORMWATER MANAGEMENT TECHNIQUES

The land use for an apartment subdivision and a single-family house subdivision under the two stormwater management solutions is provided in Table A1. The infrastructure that is included in conventional stormwater management (CSM) and low-impact development (LID) is listed in Table A2, which also summarizes the cost and corresponding provider of this infrastructure. The cost is calculated using a tool developed by the Center for Neighborhood Technology (http://greenvalues.cnt.org/national/calculator). The same tool provides maintenance costs. For single-family houses, each household pays $719 per year for CSM and $963 per year for LID. For apartment homes, each household pays $39 per year for CSM and $67 per year for LID. The government also needs to maintain existing facilities. In each single-family house subdivision, full stormwater management costs $37 per year per unit for CSM and $200 per year per unit for LID; in apartment home subdivision, these costs are $87 per year per unit for CSM and $104 per year per unit for LID. However, LID provides extra benefits including reduced air pollutants, more trees, reduced water from a central water plant, recreational opportunities and reduced water treatment. The economic benefits of LID are $315 per unit per year for single-family houses and $62 per unit per year for apartment homes.

Table A1. Residential subdivision land use under conventional stormwater management and low-impact development.

	Single-Family Subdivision		**Apartment Subdivision**	
	Conventional Area (ft^2)	Green Area (ft^2)	Conventional Area(ft^2)	Green Area (ft^2)
Conventional Roof	59,136	59,136	60,000	60,000
Streets	74,410	58,186	107,765	93,173

Roadside Swales	0	16,224	0	14,592
Driveway and Alleys	24,552	0	0	0
Permeable Driveway and Alleys	0	24,552	0	0
Sidewalks	28,392	0	25,536	0
Permeable Sidewalks	0	28,392	0	25,536
Private Yard	235,752	235,752	0	0
Open Space	13,358	11,348	242,300	126,179
Native Vegetation	0	0	0	84,120
Rain Garden	0	2,000	0	2,000
Filter Strips	0	0	0	30,000
Trees	0	0(50 trees)	0	0 (60 trees)
Total Impervious	186,490	108,332	193,301	161,173
Total Pervious	249,110	328,278	242,300	294,427

Table A2. Cost of stormwater management and corresponding providers with/without impact fees.

Items	**Conventional Stormwater Management**		**Low Impact Development**		**Providers (Impact fee)**	**Providers (No impact fee)**
	Single-Family Subdivision	**Apartment Subdivision**	**Single-Family Subdivision**	**Apartment Subdivision**		
Concrete Sidewalk	$147,354	$132,532	$0	$0	Developer	Developer
Concrete Driveway	$127,425	$0	$0	$0	Developer	Developer
Curbs and Gutters	$73,347	$106,226	$3,381	$43,298	Developer	Developer
Street	$322,195	$466,662	$251,945	$380,108	Developer	Developer
Underground Detention Tank	$628,898	$628,898	$40,496	$0	Government	Government
Permeable Pavement- Porous Asphalt*	$0	$0	$155,660	$0	Developer	Government
Permeable Pavement- Porous Concrete*	$0	$0	$170,352	$153,216	Developer	Government
Turf **	$52,313	$50,883	$51,893	$26,498	Developer	Government
Native Plants	$0	$0	$0	$8,412	Government	Government
Rain Garden	$0	$0	$14,000	$14,000	Government	Government
Roadside Swales	$0	$0	$243,360	$218,880	Government	Government
Downspout Disconnection	$0	$0	$70	$70	Government	Government
Rain Barrels*	$0	$0	$10,900	$0	Developer	Government
Cisterns*	$0	$0	$58,000	$79,750	Developer	Government
Trees	$0	$0	$13,750	$16,500	Government	Government
Tree Box Filters	$0	$0	$177,776	$213,331	Government	Government
Vegetated Filter Strips	$0	$0	$0	$43,500	Government	Government
Additional Soil	$0	$0	$88,000	$105,600	Government	Government

Note:

***** These items should be built during the construction phase. If not, the government must the replacement. Therefore, the impact fee is applied.

****** The cost of turf in the single-family subdivision is paid mainly by the developer because of large area of private yards. In the apartment subdivision, the government pays the cost of turf because of large area of public open space.

APPENDIX B

DESIGN OF SURVEY

Georgia Institute of Technology

Sustainable Residential Development: Transit-oriented and Low-impact Development

Target of This Survey

In this survey, we would like to demonstrate some designs of residential communities to you and wish to get some ideas of your choice.

***1. Please decide whether you plan to buy or rent a house/an apartment and keep in mind of your role to answer the following question.**

○ Rent ○ Buy

***2. Please write down the total housing square footage (excluding the basement, attics, and garages), the number of bedrooms and bathrooms you are looking for.**

Housing Square Footage (sq.ft) ________

Number of Bedrooms ________

Number of Bathrooms ________

***3. Please write down the house price or the rent you would like to pay for your living in the metro Atlanta.**
(This is an important parameter in our research. Please give us a reasonable number.)

House price ($) ________

Rent ($/month) ________

Next

Sustainable Residential Development: Transit-oriented and Low-impact Development

Transit-oriented Development

In this page, we will briefly introduce one of design features: transit-oriented development.

The transit-oriented development (TOD) is a mixed-use residential and commercial area designed to maximize access to public transport, and often incorporates features to encourage transit ridership. A TOD neighborhood typically has a center with a transit station or stop (train station, metro station, tram stop, or bus stop), surrounded by relatively high-density development with progressively lower-density development spreading outward from the center. The TOD is generally located within a radius of one-quarter to one-half mile (400 to 800 m) from a transit stop, as this is considered to be an appropriate scale for pedestrians, thus solving the last mile problem.

***4. Are you willing to take the public transportation instead of driving if public transportation (transit for the long distance travel plus bus for the short distance travel) is available for you and cost you almost the same time to your workplace as you drive a car,**

○ Yes

○ Probably Yes

○ Probably Not

○ No

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Low-impact Development for Building Design

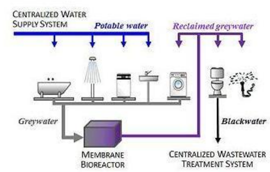
In this page, we will briefly introduce the low-impact development for sustainable water environment, which includes rainwater harvesting, wastewater reclamation, green roof, and low-impact development landscape (i.e.,porous pavement,rain garden and native vegetation).

Rainwater Harvesting for Low-density Community (i.e., Single-family house, Semi-detached house)

Cisterns, tanks or other large containers are designed to capture and store rainwater from rooftops. By temporarily holding the rain, they help the sewer systems to be less overwhelmed on rainy days. These containers may be above or below ground, and they may drain by gravity or be pumped. They are also designed to overflow into the sewer system as needed during heavy rains. Stored water can be slowly released to a natural area where it can soak into the ground or be reused in some manner on the property. There are a wide variety of reuses for rainwater that can help reduce a property's water bill as well as its stormwater fee. Some example uses are for cooling HVAC systems, washing machines, toilets, showers or various other needs based on the property.

Rainwater harvesting system is suitable for low-density development (e.g., single-family or semi-detached houses) given enough rooftop area per person for rainwater collection. In the Metro Atlanta, the collected rainwater can supply 60% of total water demand on average.

Onsite Wastewater Reclamation System for Median and High-density Community



Water reclamation is a process by which wastewater from homes is cleaned using biological and chemical treatment so that the water can be returned for non potable uses safely such as washing cars, flushing toilets, cooling water for power plants, concrete mixing, and artificial lakes.

The onsite wastewater reclamation system is suitable for mid- and high-density development because of the increasing cost-effectiveness as the number of users increases. In the Metro Atlanta, wastewater reclamation can supply 60% of total water demand on average.

Green Roof for Median and High-density Community

A green roof is a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. Green roofs serve several purposes for a building, such as absorbing rainwater, providing insulation, creating a habitat for wildlife, reducing building energy consumption, and helping to lower urban air temperatures and mitigate the heat island effect.

Green roof is suitable for mid- and high-density development because of the increasing cost-effectiveness asthe number of users increases. The installation of green roof can save 50% of energy consumption on average.

***5. Are you willing to pay more for these green designs?**

- Yes
- Probably Yes
- Probably Not
- No

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Low-impact Development for Public Green Space and Private Yard

Low-impact Development Landscape

"Low-impact Development Landscape" generally refers to landscape practices that mimic or use natural processes to maintain the hydrological and ecological functions. The practices include rain garden, permeable surface pavement, and native vegetations.

Rain Garden

Rain gardens are bowl-shaped gardens filled with native plants. Runoff from a disconnected roof downspout collects in the bowl and infiltrates into the soil with the help of the long-rooted native plants. Rain gardens are a simple and affordable technique that communities can use to reduce damage from flooding and drainage overflow. The native plants in rain gardens provide valuable wildlife habitat and reduce irrigation needs and maintenance costs in comparison to traditional forms of landscaping.

Permeable Pavement on Parking, Driveways, and Sidewalks

Permeable pavement systems are hardscape materials that allow liquids to infiltrate through void spaces in the material, or through open spaces between components of the material, while maintaining the functionality of an impervious surface. All of the permeable pavement systems have an aggregate base in common which provides structural support, runoff storage, and pollutant removal through filtering and adsorption.

Native vegetation

Native vegetation refers to plant species that were growing naturally in an area before humans introduced plants from distant places. They evolved to survive in the soil, moisture, and weather conditions of a particular location and are vigorous and hardy, with an increased ability to survive winter cold and summer heat. They are resistant to most pests and diseases. Once established, they require no irrigation or fertilization, thereby increasing water conservation through reduced irrigation and protecting water quality by eliminating the lawn pollutants that otherwise are carried into local water bodies via stormwater runoff. Native plants provide food and shelter for birds, butterflies and other desirable wildlife, allowing biodiversity to thrive even in highly urbanized areas. Many help to enrich the soil and their root systems help rainfall percolate into the soil, reducing erosion and runoff. The diversity of native plants includes interesting flowers and foliage. Native shrubs and trees provide a variety of heights, shapes and textures in the landscape and contribute to defining a unique sense of place for any landscape.

***6. If the developer implements these alternative designs on public green space in your community and/or your private yard, are you willing to pay more?**

- ◯ Yes
- ◯ Probably Yes
- ◯ Probably Not
- ◯ No

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	8 story midrise stacked flats over 2 level parking podium, 1,200 sq.ft habitable area 	16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq.ft habitable area 
Green Building Design	Rainwater harvesting	No	No	No
Accessibility to Food, Shopping and Entertainment	Driving in 30 min	Driving in 30 min	Walking in 10 min	Biking in 20 min
Size of Public Green Space	Half an acre	Half an acre	One acre	No green space
Porous Pavement Rain Garden Native Vegetation	YES for private yard	YES for public green space	No	No
Commute Mode and Time to Work/School	Public transportation (e.g., transit, bus) within 30 min	Biking within 20 min	Walking within 15 min	Car only, more than 40 min
GreatSchool Rating	Middle	High	Low	High
Walking Distance to Transit Station	Less than 20 min	Less than 10 min	More than 20 min	Less than 10 min
House Price (or Rent) Compared to your willingness to pay	20% more	10% less	20% less	10% more

***7. Please select the best desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

***8. Please select the least desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	Row house, 3 stories, 1,800 sq. ft habitable area 	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 
Green Building Design	Rainwater harvesting	Rainwater harvesting	Green roof Wastewater reclamation	Rainwater harvesting
Accessibility to Food, Shopping and Entertainment	Walking in 10 min	Walking in 10 min	Driving in 30 min	Biking in 20 min
Size of Public Green Space	No green space	One acre	Half an acre	Half an acre
Porous Pavement Rain Garden Native Vegetation	YES for private yard	YES for both public green space and private yard	YES for public green space	No
Commute Mode and Time to Work/School	Public transportation (e.g., transit, bus) within 30 min	Biking with 20 min	Public transportation (e.g., transit, bus) within 40 min	Car only within 40 min
GreatSchool Rating	Low	High	Middle	Low
Walking Distance to Transit Station	Less than 10 min	More than 20 min	Less than 20 min	Less than 20 min
House Price (or Rent) Compared to your willingness to pay	20% more	10% less	20% less	The same

***9. Please select the best desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

***10. Please select the least desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq.ft habitable area 	4 story stacked flats elevator & corridor access around1 level parking podium, 1,200 sq.ft habitable area 	Row house, 3 stories, 1,800 sq. ft habitable area 	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 
Green Building Design	Green roof Wastewater reclamation	No	Green roof Wastewater reclamation	Rainwater harvesting
Accessibility to Food, Shopping and Entertainment	Biking in 20 min	Walking in 10 min	Driving in 30 in	Waling in 10 min
Size of Public Green Space	One acre	Half an acre	Five acres	Five acres
Porous Pavement Rain Garden Native Vegetation	No	No	YES for public green space	No
Commute Mode and Time to Work/School	Car only, more than 40 min	Public transportation (e.g., transit, bus) within 30 min	Car only within 40 min	Public transportation (e.g., transit, bus) within 40 min
GreatSchool Rating	High	High	Low	Low
Walking Distance to Transit Station	Less than 10 min	Less than 20 min	More than 20 min	Less than 10 min
House Price (or Rent) Compared to your willingness to pay	20% more	10% more	10% less	20% less

∗11. Please select the best desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

∗12. Please select the least desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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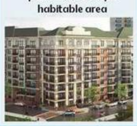
Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	8 story midrise stacked flats over 2 level parking podium, 1,200 sq.ft habitable area 	4 story stacked flats elevator & corridor access around1 level parking podium, 1,200 sq.ft habitable area 	8 story midrise stacked flats over 2 level parking podium, 1,200 sq.ft habitable area 	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 
Green Building Design	Green roof Wastewater reclamation	No	No	No
Accessibility to Food, Shopping and Entertainment	Walking in 10 min	Driving in 30 min	Biking in 20 min	Walking in 10 min
Size of Public Green Space	Half an acre	One acre	Five acres	No green space
Porous Pavement Rain Garden Native Vegetation	No	No	YES for public green space	YES for private yard
Commute Mode and Time to Work/School	Public transportation (e.g., transit, bus) within 40 min	Car only, within 40 min	Public transportation (e.g., transit, bus) within 30 min	Biking within 20 min
GreatSchool Rating	High	Middle	High	Low
Walking Distance to Transit Station	More than 20 min	Less than 10 min	Less than 20 min	More than 20 min
House Price (or Rent) Compared to your willingness to pay	20% less	The same	10% less	20% more

∗13. Please select the best desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

∗14. Please select the least desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	8 story midrise stacked flats over 2 level parking podium, 1,200 sq.ft habitable area 	Row house, 3 stories, 1,800 sq. ft habitable area 	16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq.ft habitable area 
Green Building Design	Rainwater harvesting	Green roof Wastewater reclamation	Green roof Wastewater reclamation	Green roof Wastewater reclamation
Accessibility to Food, Shopping and Entertainment	Driving in 30 min	Biking in 20 min	Walking in 10 min	Driving in 30 min
Size of Public Green Space	One acre	Half an acre	One acre	No green space
Porous Pavement Rain Garden Native Vegetation	YES for both public open space and private yard	YES for public open space	No	No
Commute Mode and Time to Work/School	Car only, more than 40 min	Biking within 20 min	Public transportation (e.g., transit, bus) within 30 min	Public transportation (e.g., transit, bus) within 40 min
GreatSchool Rating	Middle	Low	High	Middle
Walking Distance to Transit Station	More than 20 min	Less than 10 min	Less than 10 min	Less than 20 min
House Price (or Rent) Compared to your willingness to pay	20% less	10% more	20% more	10% less

***15. Please select the best desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

***16. Please select the least desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	8 story midrise stacked flats over 2 level parking podium, 1,200 sq.ft habitable area 	Row house, 3 stories, 1,800 sq. ft habitable area 
Green Building Design	No	No	Green roof Wastewater reclamation	No
Accessibility to Food, Shopping and Entertainment	Walking in 10 min	Driving in 30 min	Walking in 10 min	Biking in 20 min
Size of Public Green Space	One acre	Half an acre	Five acres	Half an acre
Porous Pavement Rain Garden Native Vegetation	YES for public green space	YES for private yard	No	Yes for public green space
Commute Mode and Time to Work/School	Car only, more than 40 min	Biking within 20 min	Car only, more than 40 min	Public transportation (e.g., transit, bus) within 30 min
GreatSchool Rating	Low	High	Middle	Middle
Walking Distance to Transit Station	Less than 20 min	Less than 10 min	Less than 20 min	More than 20 min
House Price (or Rent) Compared to your willingness to pay	10% more	20% less	10% less	The same

***17. Please select the best desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

***18. Please select the least desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	8 story midrise stacked flats over 2 level parking podium, 1,200 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq.ft habitable area 
Green Building Design	No	Green roof Wastewater reclamation	Rainwater harvesting	Green roof Wastewater reclamation
Accessibility to Food, Shopping and Entertainment	Biking in 20 min	Driving in 30 min	Biking in 20 min	Walking in 10 min
Size of Public Green Space	Half an acre	One acre	One acre	Five acres
Porous Pavement Rain Garden Native Vegetation	No	YES for public green space	No	YES for public green space
Commute Mode and Time to Work/School	Public transportation (e.g., transit, bus) within 40 min	Public transportation (e.g., transit, bust) within 30 min	Biking with 20 min	Walking within 15 min
GreatSchool Rating	Low	High	Middle	Middle
Walking Distance to Transit Station	More than 20 min	Less than 10 min	Less than 20 min	More than 20 min
House Price (or Rent) Compared to your willingness to pay	10% less	The same	20% less	10% more

***19. Please select the best desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

***20. Please select the least desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq.ft habitable area 	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	Row house, 3 stories, 1,800 sq. ft habitable area 
Green Building Design	Green roof Wastewater reclamation	No	No	No
Accessibility to Food, Shopping and Entertainment	Biking in 20 min	Driving in 30 min	Walking in 10 min	Driving in 30 min
Size of Public Green Space	One acre	Half an acre	Five acres	Five acres
Porous Pavement Rain Garden Native Vegetation	YES for public green space	YES for public green space	YES for both public green space and private yard	No
Commute Mode and Time to Work/School	Public transportation (e.g., transit, bus) within 30 min	Walking within 15 min	Public transportation (e.g., transit, bus) within 40 min	Car only, within 40 min
GreatSchool Rating	Low	High	Middle	High
Walking Distance to Transit Station	More than 20 min	Less than 20 min	More than 20 min	Less than 10 min
House Price (or Rent) Compared to your willingness to pay	20% less	20% more	The same	10% more

***21. Please select the best desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

***22. Please select the least desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 
Green Building Design	Rainwater harvesting	No	Rainwater harvesting	No
Accessibility to Food, Shopping and Entertainment	Walking in 10 min	Driving in 30 min	Walking in 10 min	Biking in 20 min
Size of Public Green Space	Half an acre	Five acres	One acre	No green space
Porous Pavement Rain Garden Native Vegetation	YES for public green space	No	YES for public green space	No
Commute Mode and Time to Work/School	Car only, more than 40 min	Biking within 20 min	Car only, within 40 min	Walking within 15 min
GreatSchool Rating	High	Low	Low	Middle
Walking Distance to Transit Station	Less than 10 min	Less than 20 min	Less than 10 min	More than 20 min
House Price (or Rent) Compared to your willingness to pay	10% less	The same	10% more	20% less

∗23. Please select the best desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

∗24. Please select the least desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	4 story stacked flats elevator & corridor access aroundt level parking podium, 1,200 sq.ft habitable area 	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 
Green Building Design	Green roof Wastewater reclamation	Rainwater harvesting	Rainwater harvesting	No
Accessibility to Food, Shopping and Entertainment	Biking in 20 min	Driving in 30 min	Walking in 10 min	Biking in 20 min
Size of Public Green Space	One acre	No green space	Half an acre	Five acres
Porous Pavement Rain Garden Native Vegetation	YES for public green space	No	YES for both public green space and private yard	YES for private yard
Commute Mode and Time to Work/School	Walking within 15 min	Biking within 20 min	Car only, more than 40 min	Car only, within 40 min
GreatSchool Rating	Middle	Middle	Low	High
Walking Distance to Transit Station	Less than 10 min	More than 20 min	Less than 10 min	Less than 20 min
House Price (or Rent) Compared to your willingness to pay	20% more	10% more	The same	20% less

∗25. Please select the best desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

∗26. Please select the least desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	8 story midrise stacked flats over 2 level parking podium, 1,200 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 
Green Building Design	No	Rainwater harvesting	No	No
Accessibility to Food, Shopping and Entertainment	Walking in 10 min	Biking in 20 min	Driving in 30 min	Biking in 20 min
Size of Public Green Space	Five acres	One acre	Half an acre	No green space
Porous Pavement Rain Garden Native Vegetation	YES for public open space	YES for private yard	No	YES for private yard
Commute Mode and Time to Work/School	Public transportation (e.g., transit, bus) within 30 min	Public transportation (e.g., transit, bus) within 40 min	Car only, more than 40 min	Walking within 15 min
GreatSchool Rating	Middle	High	Middle	Low
Walking Distance to Transit Station	Less than 10 min	Less than 20 min	More than 20 min	Less than 20 min
House Price (or Rent) Compared to your willingness to pay	20% less	10% more	20% more	10% less

***27. Please select the best desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

***28. Please select the least desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Row house, 3 stories, 1,800 sq. ft habitable area 	4 story stacked flats elevator & corridor access aroundt level parking podium, 1,200 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 
Green Building Design	No	Green roof Wastewater reclamation	Rainwater harvesting	Rainwater harvesting
Accessibility to Food, Shopping and Entertainment	Walking in 10 min	Driving in 30 min	Biking in 20 min	Driving in 30 min
Size of Public Green Space	One acre	One acre	No green space	Five acres
Porous Pavement Rain Garden Native Vegetation	YES for public green space	No	YES for private yard	No
Commute Mode and Time to Work/School	Biking within 20 min	Public transportation (e.g., transit, bus) within 30 min	Car only, within 40 min	Walking within 15 min
GreatSchool Rating	Middle	Low	Middle	High
Walking Distance to Transit Station	Less than 20 min	More than 20 min	Less than 10 min	More than 20 min
House Price (or Rent) Compared to your willingness to pay	20% more	10% less	20% less	The same

***29. Please select the best desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

***30. Please select the least desirable community you would like to live in.**

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	Single-family house, 2 stories, 5,000 sq.ft lot size, 2,400 sq.ft habitable area 	Row house, 3 stories, 1,800 sq. ft habitable area 	16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq.ft habitable area 	Row house, 3 stories, 1,800 sq. ft habitable area 
Green Building Design	No	Green roof Wastewater reclamation	No	No
Accessibility to Food, Shopping and Entertainment	Driving in 30 min	Biking in 20 min	Walking in 10 min	Driving in 30 min
Size of Public Green Space	One acre	Five acres	Half an acre	Five acres
Porous Pavement Rain Garden Native Vegetation	YES for private yard	No	YES for public green space	YES for public green space
Commute Mode and Time to Work/School	Public transportation (e.g., transit, bus) within 40 min	Biking within 20 min	Car only, within 40 min	Car only, more than 40 min
GreatSchool Rating	Middle	Middle	High	Low
Walking Distance to Transit Station	Less than 10 min	Less than 10 min	More than 20 min	Less than 20 min
House Price (or Rent) Compared to your willingness to pay	10% more	The same	20% more	20% less

∗31. Please select the best desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

∗32. Please select the least desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Discrete Choice Experiment (Fourteen Scenarios in Total)

Here are four community designs. Please select the most and least desirable community you want to live in.

Please read the four descriptions below and answer the following two questions.

Choice ID	1	2	3	4
Housing Design	16 story, 160' high high-rise stacked flats over 3-4 level parking podium, 1,200 sq.ft habitable area 	4 story stacked flats elevator & corridor access aroundt level parking podium, 1,200 sq.ft habitable area 	Semi-detached house, 2 stories, 3,000 sq.ft lot size, 2,400 sq.ft habitable area 	4 story stacked flats elevator & corridor access aroundt level parking podium, 1,200 sq.ft habitable area 
Green Building Design	No	No	No	Green roof Wastewater reclamation
Accessibility to Food, Shopping and Entertainment	Walking in 10 min	Biking in 20 min	Driving in 30 min	Walking in 10 min
Size of Public Green Space	Half an acre	Five acres	Five acres	No green space
Porous Pavement Rain Garden Native Vegetation	No	YES for public open space	YES for private yard	No
Commute Mode and Time to Work/School	Walking within 15 min	Public transportation (e.g., transit, bus) within 40 min	Public transportation (e.g., transit, bus) within 30 min	Car only, within 40 min
GreatSchool Rating	Middle	Low	Middle	High
Walking Distance to Transit Station	Less than 10 min	More than 20 min	More than 20 min	Less than 20 min
House Price (or Rent) Compared to your willingness to pay	10% less	20% more	10% more	The same

∗33. Please select the best desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

∗34. Please select the least desirable community you would like to live in.

○ Choice 1 ○ Choice 2 ○ Choice 3 ○ Choice 4

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Demographic Information

In this page, we will ask for some demographic information. Please be aware that the data we are collecting will not be able to identify you and we will keep it safely.

***35. Do you rent or own the place where you live?**

- Own
- Rent

***36. In which type of housing do you currently live?**

- Apartment
- Condominium
- Townhouse
- Duplex
- Houseboat
- Military housing
- Mobile home
- Single-family house

***37. What is your ethnicity? (Please select all that apply.)**

- American Indian or Alaskan Native
- Asian or Pacific Islander
- Black or African American
- Hispanic or Latino
- White / Caucasian
- Prefer not to answer

***38. What is your gender?**

- Female
- Male

***39. What is the highest level of education you have completed?**

***40. What is your age?**

- 18 to 24
- 25 to 34
- 35 to 44
- 45 to 54
- 55 to 64
- 65 to 74
- 75 or older

***41. How many people currently live in your household?**

***42. Are you the head of household?**

- Yes
- No

***43. Do you have any children under 18?**

- Yes
- No

***44. What is your approximate average household income?**

- $0-$24,999
- $25,000-$49,999
- $50,000-$74,999
- $75,000-$99,999
- $100,000-$124,999
- $125,000-$149,999
- $150,000-$174,999
- $175,000-$199,999
- $200,000 and up

***45. Which of the following categories best describes your employment status?**

- Employed
- Self-employed
- Disabled, not able to work
- Student
- Not employed
- Retired

***46. In a typical week, how many miles do you drive your car (excluding the miles for work)?**

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Traffic behavior

*47. In what ZIP code is your workplace (or school) located? (enter 5-digit ZIP code; for example, 00544 or 94305)

*48. How long does it take you to get to the workplace (or school) on average?

- Less than 10 min
- 10 min to 20 min
- 20 min to 30 min
- 30 min to 40 min
- 40 min to 50 min
- 50 min to 1 hour
- More than 1 hour
- Work at home

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Sustainable Residential Development: Transit-oriented and Low-impact Development

Thank you for your time and effort

*49. Please write down your worker ID of Mechanical Turk so we can find your work.

*50. Please write down one word here and you need to write down the same word as survey code on Mechanical Turk interface when you submit the task for the review (Be aware of the letter case).

Prev Done

APPENDIX C

MOVER RATE IN THE METRO ATLANTA

In 1995, the population in the metro Atlanta was 3,630,747. Non-movers occupying same residences from 1995 to 2000 in the metro Atlanta were 1,769,531 according to the gross migration rate of Metropolitan Statistical Areas.[113] The yearly mover rate is determined by Eq. C.1.

$$Pop_{1995} \times \left[1-(r+(1-r)\times r+(1-r)^2\times r+(1-r)^3\times r+(1-r)^4\times r\right] = Pop_{2000} \quad \text{(C.1)}$$

where, Pop_{1995} is the population of metro Atlanta in 1995, Pop_{2000} is the non-movers in 2000, and r is mover rate.

According to Eq. C.1, the yearly mover rate is 13.0% in the metro Atlanta. The average annual mover rate between 2012 and 2013 is 11.7% in the U.S.[114] I assumed no significant difference in mover rate between the U.S. and metro Atlanta, and the mover rate remains relatively stable in the metro Atlanta. So I adopted 13.0% yearly mover rate in Chapter 5.

Given the fact that 8% of housing units in the metro Atlanta belong to 20 or more unit structure (Appendix D), I consider 92% of total households in 2013 as existing single-family households and these households have a potential demand for high density communities (i.e., 4-story apartment home) when they relocate in the future. Thus, the number of existing single-family households to relocate in 2014 is 12% (i.e., 92%×13%) of the total households in 2013, which equals 231,370.

APPENDIX D

HOUSING TYPE IN THE METRO ATLANTA

In 2012, there are 8% of housing units in 20 or more unit structure in the metro Atlanta. It is equivalent to saying that 8% of annual supply of housing units belong to 20 or more unit structure. Considering the 20 or more unit structure close to a 4-story apartments, I assume that 92% of housing units are built in low-density communities (i.e., single-family house community in Figure 5.1) and 8% of housing units built are built in high-density communities (i.e., 4-story apartment community in Figure 5.1) in the starting year of running the ABM.

APPENDIX E

COST OF LOW-IMPACT DEVELOPMENT

Table E1. Construction cost of managing stormwater water in apartment communities and the impact on housing price.

Construction Cost ($)	Conventional	Green	Difference (Green – Conventional)
Concrete Sidewalk	$132,532	$0	-$132,532
Curbs and Gutters	$106,226	$0	-$106,226
Street	$466,622	$386,630	-$79,992
Conventional Stormwater Storage	$419,265	$0	-$419,265
Standard Roof	$450,000	$360,000	-$90,000
Green Roof	$0	$189,000	$189,000
Permeable Sidewalk - Porous Asphalt	$0	$161,898	$161,898
Turf	$50,883	$25,126	-$25,756
Native Plants	$0	$11,965	$11,965
Rain Garden	$0	$21,000	$21,000
Roadside Swales	$0	$277,110	$277,110
Downspout Disconnection	$0	$35	$35
Wastewater Reclamation (Xpress™ Membrane Biological Reactor Packaged Plants)[115]	$0	$428,288	$428,288
Total Cost	$1,625,528	$1,861,052	$235,524
Apartment Price			$144,262
Increase In Price			0.9%

Table E2. Construction cost of managing stormwater water in single-family house communities based on "home-based LID" policy and the impact on housing price.

Construction Cost ($)	Conventional	Green	Difference (Green – Conventional)
Concrete Sidewalk	$147,354	$0	-$147,354
Concrete Driveway	$127,425	$0	-$127,425
Curbs and Gutters	$73,347	$3,381	-$69,966
Street	$322,195	$269,508	-$52,687
Conventional Stormwater Storage	$419,265	$0	-$419,265
Standard Roof	$443,520	$443,520	$0

Permeable Sidewalk-Porous Asphalt	$0	$180,005	$180,005
Permeable Driveway-Porous Concrete	$0	$147,312	$147,312
Turf	$52,313	$52,313	$0
Native Plants	$0	$6,160	$6,160
Rain Garden	$0	$15,400	$15,400
Roadside Swales	$0	$182,520	$182,520
Downspout Disconnection	$0	$3,080	$3,080
Rain Barrels	$0	$47,960	$47,960
Vegetated Filter Strips	$0	$25,520	$25,520
Total cost	$1,585,419	$1,376,679	-$208,740
Single-family House Price			$336,270
Increase In Price			-1.41%

Table E3. Construction cost of managing stormwater water in single-family house communities based on "community-based LID" policy and the impact on housing price.

Construction Cost ($)	Conventional	Green	Difference (Green – Conventional)
Concrete Sidewalk	$147,354	$0	-$147,354
Concrete Driveway	$127,425	$0	-$127,425
Curbs and Gutters	$73,347	$3,381	-$69,966
Street	$322,195	$269,508	-$52,687
Conventional Stormwater Storage	$419,265	$0	-$419,265
Standard Roof	$443,520	$443,520	$0
Permeable Sidewalk-Porous Asphalt	$0	$180,005	$180,005
Permeable Driveway-Porous Concrete	$0	$147,312	$147,312
Turf	$52,313	$25,894	-$26,419
Native Plants	$0	$12,331	$12,331
Rain Garden	$0	$17,500	$17,500
Roadside Swales	$0	$182,520	$182,520
Downspout Disconnection	$0	$70	$70
Rain Barrels	$0	$43,600	$43,600
Total Cost	$1,585,419	$1,325,641	-$259,778
Single-family House Price			$336,270
Increase In Price			-1.76%

The cost of stormwater management is estimated by the same tool in Appendix A. I assume that the developer pays the cost of stormwater management as required by the policy of managing the first one inch runoff over the whole community. The price of apartment homes and single-family houses is estimated using the tool developed by National Association of Home Builders.[53, 54]

APPENDIX F

SELECTION OF THE NUMBER OF CLASSES

The prediction error indicates how well the observed choices are predicted by the model. The prediction error is obtained as follows:

$$Error = \frac{\sum_{1}^{I}\sum_{t}^{T} Error_{it}}{I \times T} \tag{F.1}$$

where, I is the number of respondents, whose responses are used as training data to run the latent-class choice model; T is the number of responses to scenarios from the respondent i.

In the computation of prediction error, $Error_{it}$ equals 0 if the model prediction is correct in terms of the best choice and 1 otherwise.

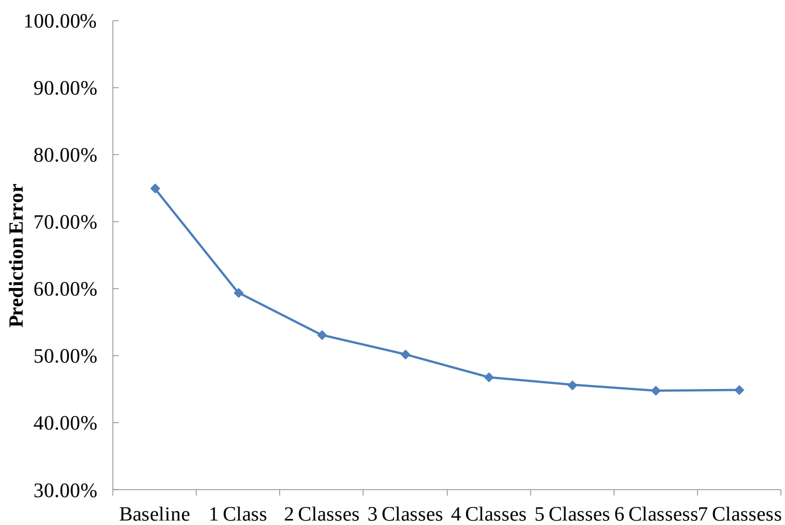

Figure F.1. Prediction error of the latent class choice model with difference number of classes. In the case of "Baseline", the probability of each option to be chosen as the best is constant, which is ¼ in this study. Accordingly, the prediction error is 75%, or 1-1/4.

REFERENCES

1. Brown, M. A.; Southworth, F., Mitigating climate change through green buildings and smart growth. *Environment and Planning A* **2008,** *40*, (3), 653-675.
2. Gonzalez, G. A., Urban sprawl, global warming and the limits of ecological modernisation. *Environ. Polit.* **2005,** *14*, (3), 344-362.
3. Martins, H., Urban compaction or dispersion? An air quality modelling study. *Atmospheric Environment* **2012,** *54*, 60-72.
4. Stone, B.; Hess, J. J.; Frumkin, H., Urban form and extreme heat events: are sprawling cities more vulnerable to climate change than compact cities? *Environ. Health Perspect.* **2010,** *118*, (10), 1425-1428.
5. Ewing, R., Is Los Angeles-style sprawl desirable? *Journal of the American Planning Association* **1997,** *63*, (1), 107-126.
6. Johnson, M. P., Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. *Environment and Planning A* **2001,** *33*, (4), 717-735.
7. Bettencourt, L.; West, G., A unified theory of urban living. *Nature* **2010,** *467*, (7318), 912-913.
8. Cities: The century of the city. *Nature* **2011,** *467*, (7318), 900-1.
9. *Green infrastructure for Los Angeles: addressing urban runoff and water supply through low impact development*; City of Los Angeles, 2009.
10. Cook, E. A., GREEN SITE DESIGN: STRATEGIES FOR STORM WATER MANAGEMENT. *J. Green Build.* **2007,** *2*, (4), 46-56.
11. *The triple bottom line assessment of traditioinal and green infrastructure options for controlling CSO events in Philadelphia's watersheds*; City of Philadelphia, 2009.
12. Schmitz, N. J. Open Space In Residential Subdivsions: Effect of Low Impact Development and Open space on Single-Family Housing Values. University of Nebraska, Omaha, Nebraska, 2008.
13. Litman, T. *Evaluating public transit benefits and costs*; Victoria Transport Policy Institute: 2012.
14. Suzuki, H.; Cervero, R.; Iuchi, K., *Transforming cities with transit: Transit and land-use integration for sustainable urban development*. World Bank Publications: 2013.
15. *Transit-oriented development in the Chicago region: efficient and resilient communities for the 21st century*; The center for neighborhood technology: 2013.
16. *Marta transit-oriented development guidelines*; Marta: 2010.
17. Montalto, F.; Behr, C.; Alfredo, K.; Wolf, M.; Arye, M.; Walsh, M., Rapid assessment of the cost-effectiveness of low impact development for CSO control. *Landsc. Urban Plan.* **2007,** *82*, (3), 117-131.
18. Francis, M., Village Homes: A Case Study In Community Design. *Landscape Journal* **2002,** *21*, (1), 23-41.
19. Miller, J. H.; Page, S. E., *Complex Adaptive Systems: An Introduction to Computational Models of Social Life*. Princeton University Press: 2007.
20. Trantopoulos, K.; Schlapfer, M.; Helbing, D., Toward Sustainability of Complex Urban Systems through Techno-Social Reality Mining. *Environ. Sci. Technol.* **2011,** *45*, (15), 6231-6232.

21. Mell, I. C.; Henneberry, J.; Hehl-Lange, S.; Keskin, B., Promoting urban greening: Valuing the development of green infrastructure investments in the urban core of Manchester, UK. *Urban Forestry & Urban Greening* **2013,** *12*, (3), 296-306.
22. Bowman, T.; Tyndall, J. C.; Thompson, J.; Kliebenstein, J.; Colletti, J. P., Multiple approaches to valuation of conservation design and low-impact development features in residential subdivisions. *J. Environ. Manage.* **2012,** *104*, 101-113.
23. Leinberger, C. *The WalkUP wake-up call: Atlanta*; The Georgia Washington University: 2013.
24. Zhang, Y. L.; Wu, Y. Y.; Yu, H.; Dong, Z. F.; Zhang, B., Trade-offs in designing water pollution trading policy with multiple objectives: A case study in the Tai Lake Basin, China. *Environmental Science & Policy* **2013,** *33*, 295-307.
25. Nguyen, N. P.; Shortle, J. S.; Reed, P. M.; Nguyen, T. T., Water quality trading with asymmetric information, uncertainty and transaction costs: A stochastic agent-based simulation. *Resource and Energy Economics* **2013,** *35*, (1), 60-90.
26. Bakam, I.; Balana, B. B.; Matthews, R., Cost-effectiveness analysis of policy instruments for greenhouse gas emission mitigation in the agricultural sector. *J. Environ. Manage.* **2012,** *112*, 33-44.
27. Vytelingum, P.; Ramchurn, S.; Voice, T.; Rogers, A.; Jennings, N.; Ieee, Agent-Based Modeling of Smart-Grid Market Operations. In *2011 Ieee Power and Energy Society General Meeting*, 2011.
28. Zhang, T.; Gensler, S.; Garcia, R., A Study of the Diffusion of Alternative Fuel Vehicles: An Agent-Based Modeling Approach. *J. Prod. Innov. Manage.* **2011,** *28*, (2), 152-168.
29. Schwarz, N.; Ernst, A., Agent-based modeling of the diffusion of environmental innovations - An empirical approach. *Technol. Forecast. Soc. Chang.* **2009,** *76*, (4), 497-511.
30. Filatova, T.; Parker, D.; van der Veen, A., Agent-based urban land markets: agent's pricing behavior, land prices and urban land use change. *Jasss* **2009,** *12*, (1), 29.
31. Xu, M.; Allenby, B.; Kim, J.; Kahhat, R., A Dynamic Agent-Based Analysis for the Environmental Impacts of Conventional and Novel Book Retailing. *Environ. Sci. Technol.* **2009,** *43*, (8), 2851-2857.
32. Zhang, B.; Yu, Q. Q.; Bi, J., Policy design and performance of emissions trading markets: an adaptive agent-based analysis. *Environ. Sci. Technol.* **2010,** *44*, (15), 5693-5699.
33. Parker, D. C.; Manson, S. M.; Janssen, M. A.; Hoffmann, M. J.; Deadman, P., Multi-agent systems for the simulation of land-use and land-cover change: A review. *Ann. Assoc. Am. Geogr.* **2003,** *93*, (2), 314-337.
34. O'Sullivan, D.; Haklay, M., Agent-based models and individualism: is the world agent-based? *Environment and Planning A* **2000,** *32*, (8), 1409-1425.
35. Vespignani, A., Modelling dynamical processes in complex socio-technical systems. *Nature Physics* **2012,** *8*, (1), 32-39.
36. March, J. G., Bounded rationality, ambiguity, and engineering of choice. *Bell Journal of Economics* **1978,** *9*, (2), 587-608.
37. Magliocca, N.; Safirova, E.; McConnell, V.; Walls, M., An economic agent-based model of coupled housing and land markets (CHALMS). *Comput. Environ. Urban Syst.* **2011,** *35*, (3), 183-191.

38. Roberts, D. A.; Bradley, E. S.; Cheung, R.; Leifer, I.; Dennison, P. E.; Margolis, J. S., Mapping methane emissions from a marine geological seep source using imaging spectrometry. *Remote Sensing of Environment* **2010,** *114*, (3), 592-606.
39. Consumer expenditure survey. In U.S. Bureau of Labor Statistics: 2011.
40. Levine, J.; Frank, L. D., Transportation and land-use preferences and residents' neighborhood choices: the sufficiency of compact development in the Atlanta region. *Transportation* **2007,** *34*, (2), 255-274.
41. Salathe, L. *Household expenditure patterns in the United States*; Washington,D.C., 1979.
42. Bowman, T.; Thompson, J.; Colletti, J., Valuation of open space and conservation features in residential subdivisions. *J. Environ. Manage.* **2009,** *90*, (1), 321-330.
43. Geoghegan, J., The value of open spaces in residential land use. *Land Use Pol.* **2002,** *19*, (1), 91-98.
44. Kopits, E.; Mcconnell, V.; Walls, M., Big yards or green space? *Regulation* **2008,** *31*, (3).
45. McConnell, V.; Walls, M. *The value of open space: evidence from studies of nonmarket benefits*; 2005.
46. Hansen, J. L.; Formby, J. P.; Smith, W. J., Estimating the income elasticity of demand for housing: A comparison of traditional and Lorenz-concentration curve methodologies. *Journal of Housing Economics* **1998,** *7*, (4), 328-342.
47. Current population survey, 2011 annual social and economic supplement. In U.S.Census Bureau: 2011.
48. Emrath, P., Breaking down house price and construction costs. In National association of home buliders: 2010.
49. Li, K.; E.Fonseca.; F.Sharif.; S.Palaniappan.; J.Crittenden., Community design towards sustainability. In *Ecocity World Summit*, San Francisco, 2008.
50. Apartment cap rate trends. In Marcus & Millichap Research Services, Costar Group, Inc., Real Capital Analytics: 2011.
51. Metro area mortgage statistics. In HSH Associated, Financial Publishers: 2012.
52. Grimm, V.; Revilla, E.; Berger, U.; Jeltsch, F.; Mooij, W. M.; Railsback, S. F.; Thulke, H. H.; Weiner, J.; Wiegand, T.; DeAngelis, D. L., Pattern-oriented modeling of agent-based complex systems: Lessons from ecology. *Science* **2005,** *310*, (5750), 987-991.
53. Emrath, P., NAHB apartment rent estimator, special study for housing economics. In National Assocation of Home Builders: 2011.
54. Emrath, P., NAHB house price estimator updated, special study for housing economics. In National Association of Home Builders: 2011.
55. Bryce, W.; Ed, M.; Sarah, R., The effect of low-impact-development on property values. *Proceedings of the Water Environment Federation, Sustainability* **2008**, 318-323(6).
56. Coffman, L. *Low-impact development: an integrated design approach*; Department of Environmental Resource Programs and Planning Division: Largo, Maryland, 1999.
57. Hinman, C. *Low impact development, technical guidance manual for puget sound*; Washington State University: 2005.

58. U.S.EPA Low Impact Development (LID) and Other Green Design Strategies. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=124
59. *A review of water conservation planning for the Atlanta, Georgia Region*; Pacific Institute for Studies in Development, Environment, and Security: Oakland, 2006.
60. Household Site End-Use Consumption in the South Region, Totals and Averages, 2009. In Energy Information Adminstration, U. S., Ed. 2009.
61. Bedan, E. S.; Clausen, J. C., Stormwater Runoff Quality and Quantity From Traditional and Low Impact Development Watersheds(1). *J. Am. Water Resour. Assoc.* **2009,** *45*, (4), 998-1008.
62. Pyke, C.; Warren, M. P.; Johnson, T.; LaGro, J.; Scharfenberg, J.; Groth, P.; Freed, R.; Schroeer, W.; Main, E., Assessment of low impact development for managing stormwater with changing precipitation due to climate change. *Landsc. Urban Plan.* **2011,** *103*, (2), 166-173.
63. Angrill, S.; Farreny, R.; Gasol, C. M.; Gabarrell, X.; Vinolas, B.; Josa, A.; Rieradevall, J., Environmental analysis of rainwater harvesting infrastructures in diffuse and compact urban models of Mediterranean climate. *Int. J. Life Cycle Assess.* **2011,** *17*, (1), 25-42.
64. Williams, E. S.; Wise, W. R., Economic Impacts of Alternative Approaches to Storm-Water Management and Land Development. *Journal of Water Resources Planning and Management-Asce* **2009,** *135*, (6), 537-546.
65. Gearheart, G. *A review of low impact development policies: removing institutional barriers to adoption*; California State Water Resources Control Board Stormwater Program,and The Water Board Academy: 2007.
66. Roy, A. H.; Wenger, S. J.; Fletcher, T. D.; Walsh, C. J.; Ladson, A. R.; Shuster, W. D.; Thurston, H. W.; Brown, R. R., Impediments and solutions to sustainable, watershed-scale urban stormwater management: Lessons from Australia and the United States. *Environ. Manage.* **2008,** *42*, (2), 344-359.
67. Burge, G.; Ihlanfeldt, K., Impact fees and single-family home construction. *Journal of Urban Economics* **2006,** *60*, (2), 284-306.
68. Russell., M. A., *Mining the social web*. O'Reilly Media, Inc: Sebastopol, U.S.A., 2011.
69. Gonzalez, M. C.; Hidalgo, C. A.; Barabasi, A. L., Understanding individual human mobility patterns. *Nature* **2008,** *453*, (7196), 779-782.
70. Malleson, N.; Birkin, M., Analysis of crime patterns through the integration of an agent-based model and a population microsimulation. *Comput. Environ. Urban Syst.* **2012,** *36*, (6), 551-561.
71. McFadden, D., The choice theory approach to market research. *Marketing Science* **1986,** *5*, (4), 275-297.
72. van Putten, I. E.; Jennings, S. M.; Louviere, J. J.; Burgess, L. B., Tasmanian landowner preferences for conservation incentive programs: A latent class approach. *Journal of Environmental Management* **2011,** *92*, (10), 2647-2656.
73. Hoyos, D., The state of the art of environmental valuation with discrete choice experiments. *Ecological Economics* **2010,** *69*, (8), 1595-1603.

74. Boxall, P. C.; Adamowicz, W. L., Understanding heterogeneous preferences in random utility models: A latent class approach. *Environmental & Resource Economics* **2002,** *23*, (4), 421-446.
75. Greene, W. H.; Hensher, D. A., A latent class model for discrete choice analysis: contrasts with mixed logit. *Transportation Research Part B-Methodological* **2003,** *37*, (8), 681-698.
76. Magidson, J.; Vermunt, J. K. *Nontechnical introduction to latent class models*; 2002.
77. Birol, E.; Karousakis, K.; Koundouri, P., Using a choice experiment to account for preference heterogeneity in wetland attributes: The case of Cheimaditida wetland in Greece. *Ecological Economics* **2006,** *60*, (1), 145-156.
78. Rid, W.; Profeta, A., Stated preferences for sustainable housing development in Germany - a latent class analysis. *Journal of Planning Education and Research* **2011,** *31*, (1), 26-46.
79. *The 2011 Community Preference Survey, What Americans are Looking for When Deciding Where to Live*; National Association of Realtors: 2011.
80. Yang, L. Y.; Zheng, G.; Zhu, X. N., Cross-nested logit model for the joint choice of residential location, travel mode, and departure time. *Habitat International* **2013,** *38*, 157-166.
81. Baltas, G.; Doyle, P., Random utility models in marketing research: a survey. *J. Bus. Res.* **2001,** *51*, (2), 115-125.
82. Lee, B. H. Y.; Waddell, P., Residential mobility and location choice: a nested logit model with sampling of alternatives. *Transportation* **2010,** *37*, (4), 587-601.
83. Bekhor, S.; Prashker, J. N., GEV-based destination choice models that account for unobserved similarities among alternatives. *Transportation Research Part B-Methodological* **2008,** *42*, (3), 243-262.
84. Olaru, D.; Smith, B.; Taplin, J. H. E., Residential location and transit-oriented development in a new rail corridor. *Transportation Research Part a-Policy and Practice* **2011,** *45*, (3), 219-237.
85. Liao, F. H.; Farber, S.; Ewing, R., Compact development and preference heterogeneity in residential location choice behaviour: A latent class analysis. *Urban Studies* **2014**.
86. Kjaer, T. A review of the discrete choice experiment with emphasis on its application in health care. University of Southern Denmark, 2005.
87. Kiel, K. A.; Zabel, J. E., Location, location, location: The 3L Approach to house price determination. *J. Hous. Econ.* **2008,** *17*, (2), 175-190.
88. *Land use and driving: the role compact development can paly in reducing greenhouse gas emissions*; Urban Land Institute: 2010.
89. Walker, J. L.; Li, J. P., Latent lifestyle preferences and household location decisions. *Journal of Geographical Systems* **2007,** *9*, (1), 77-101.
90. Smith, B.; Olaru, D., Lifecycle stages and residential location choice in the presence of latent preference heterogeneity. *Environ. Plan. A* **2013,** *45*, (10), 2495-2514.
91. Kim, T. K.; Horner, M. W.; Marans, R. W., Life cycle and environmental factors in selecting residential and job locations. *Housing Studies* **2005,** *20*, (3), 457-473.
92. Frenkel, A.; Bendit, E.; Kaplan, S., Residential location choice of knowledge-workers: The role of amenities, workplace and lifestyle. *Cities* **2013,** *35*, 33-41.

93. Xie, Y. C.; Batty, M.; Zhao, K., Simulating emergent urban form using agent-based modeling: Desakota in the suzhou-wuxian region in china. *Annals of the Association of American Geographers* **2007,** *97*, (3), 477-495.
94. Waddell, P.; Borning, A.; Noth, M.; Freier, N.; Becke, M.; Ulfarsson, G., Microsimulation of Urban Development and Location Choices: Design and Implementation of UrbanSim. *Networks & Spatial Economics* **2003,** *3*, (1), 43-67.
95. *Latent GOLD Choice*, 4.5; Statistical Innovations Inc: 2012.
96. Vermunt, J. K.; Magidson, J. *Technical guide for Latent Gold Choice 4.0: basic and advanced*; Statistical Innovations Inc: Belmont Massachusetts, 2005; pp 11-12.
97. Phaneuf, D. J.; Taylor, L. O.; Braden, J. B., Combining Revealed and Stated Preference Data to Estimate Preferences for Residential Amenities: A GMM Approach. *Land Economics* **2013,** *89*, (1), 30-52.
98. Gould, W. B., Quality of inequality - urban and suburban public schools - Daly, CU. *Cornell Law Rev.* **1969,** *55*, (1), 145-151.
99. Kim, J. H., Linking land use planning and regulation to economic development: a literature review. *J. Plan. Lit.* **2011,** *26*, (1), 35-47.
100. Nasiri, F.; Savage, T.; Wang, R.; Barawid, N.; Zimmerman, J. B., A system dynamics approach for urban water reuse planning: a case study from the Great Lakes region. *Stoch. Environ. Res. Risk Assess.* **2013,** *27*, (3), 675-691.
101. *Measuring Sprawl 2014*; Smart Growth America: 2014.
102. Katz, P., The missing metric. *Government Finance Review* 2013, pp 21-32.
103. Pandit, A.; Lu, Z.; Crittenden, J., Managing the Complexity of Urban Systems. *Journal of Industrial Ecology* **2014,** *Forthcoming*.
104. Paolacci, G.; chandler, J.; Ipeirotis, P. G., Running experiments on Amazon Mechanical TUrk. *Judgment and Decision Making* **2010,** *5*, (5), 411-491.
105. Crump, M. J. C.; McDonnell, J. V.; Gureckis, T. M., Evaluating Amazon's Mechanical Turk as a Tool for Experimental Behavioral Research. *PLoS ONE* **2013,** *8*, (3), e57410.
106. Amir, O.; Rand, D. G.; Gal, Y. a. K., Economic Games on the Internet: The Effect of $1 Stakes. *PLoS ONE* **2012,** *7*, (2), e31461.
107. *JMP*, SAS Institute Inc: 2012.
108. Najafzadeh, M.; Lynd, L. D.; Davis, J. C.; Bryan, S.; Anis, A.; Marra, M.; Marra, C. A., Barriers to integrating personalized medicine into clinical practice: a best-worst scaling choice experiment. *Genetics in Medicine* **2012,** *14*, (5), 520-526.
109. *ARC's 20-county forecasts: what the future holds*; Atlanta Regional Commission: 2009.
110. Chester, M. V.; Nahik, M. J.; Fraser, A. M.; Kimball, M. A.; Garikapati, V. M., Integrating Life-cycle Environmental and Economic Assessment with Transportation and Land Use Planning. *Environ. Sci. Technol.* **2013,** *47*, (21), 12020-12028.
111. De Sousa, M. R. C.; Montalto, F. A.; Spatari, S., Using Life Cycle Assessment to Evaluate Green and Grey Combined Sewer Overflow Control Strategies. *Journal of Industrial Ecology* **2012,** *16*, (6), 901-913.
112. Whitfield, R., Atlanta School Test Scores Heat Map. In *The Atlanta & Northside Area ~ Real Estate Finder*, 2013.
113. Metropolitan Statistica Areas Sorted by Gross Migration Rate. https://www.census.gov/population/www/cen2000/migration/metxmet/indexh.html

114. *Reason for moving: 2012 o 2013*; U.S Census: 2013.
115. EVOQUA http://www.evoqua.com/en/products/biological_treatment/membrane_biological_reactor_systems_mbr/Pages/envirex_mbr_xpress_packaged_plant.aspx